The Potter Cove coastal ecosystem, Antarctica

Synopsis of research performed within the frame of the Argentinean - German Cooperation at the Dallmann Laboratory and Jubany Station (King George Island, Antarctica, 1991-1997)

Das Küstenökosystem der Potter Cove, Antarktis

Eine Synopsis der Forschungsarbeiten im Rahmen der argentinisch - deutschen Kooperation im Dallmann-Labor und an der Jubany-Station

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TABLE OF CONTENTS

1. THE ENVIRONMENT OF POTTER COVE

2. STRUCTURE AND DYNAMICS OF THE ECOSYSTEM

3. ECOPHYSIOLOGICAL STUDIES ON KEY ORGANISMS IN THE ECOSYSTEM

4. FOOD WEB STRUCTURE AND ENERGY FLOW IN THE POTTER COVE ECOSYSTEM

5. HUMAN IMPACT AND EFFECT OF INCREASING UV-RADIATION ON THE ECOSYSTEM

The Three Brothers Hill, Potter Cove
and Jubany Station with the Dallmann Laboratory

The Dallmann Laboratory

The Potter Cove Coastal Ecosystem

Introduction

The Antarctic Treaty strongly encourages international scientific and logistic cooperation in Antarctica. During the past two decades, the Scientific Council of Antarctic Research (SCAR), through various types of working groups, has undertaken great efforts to arrive at an international approach to study the waters around the Antarctic continent. The BIOMASS project centred multidisciplinary research of many countries around the krill and its ecosystem, CCAMLR has been in charge of the multinational management of living resources, and large international and interdisciplinary research cruises were carried out within the European "Polarstern" Study (EPOS), the Joint Global Ocean Flux Study (SO-JGOFS) and the SCAR programme Ecology of the Antarctic Sea Ice Zone (EASIZ). Simultaneously, many land- and ice-based stations started opening their facilities to researchers from other countries, and international cooperation gradually began to enrich the investigations which had formerly been done by single countries.

The compilation of results from joint Argentinean-German shallow-water research in this volume is based on another, quite innovative, approach. In September 1985, an agreement of cooperation was signed in Bremerhaven between the Dirección Nacional del Antártico (DNA, Argentina) and the Alfred Wegener Institute for Polar and Marine Research (AWI). This agreement involves exchange of scientists and logistic cooperation between the AWI and the Instituto Antártico Argentino (IAA). Cooperation in the field of biology consequently started at the Argentinean base Teniente Jubany (Potter Cove, King George Island/Isla 25 de Mayo, South Shetland Islands) during the 1991-92 summer season. As an annex to Jubany, the Dallmann laboratory, named after the German whaler and explorer Eduard Dallmann who studied part of the South Polar Sea in 1873/74, was constructed as an Argentinean-German research facility, representing the only lab in the Antarctic that is jointly administrated and used by two nations. Activities at the Dallmann laboratory, which was inaugurated in January 1994 by leading scientists from both institutions, started in the 1993-94 season. Recently the Netherlands, which have provided a sewage plant for Jubany station and are participating in the purchase of a research launch, have joint Argentina and Germany as users of the Dallmann facilities.

The Dallmann laboratory contains four scientific laboratories for biological, geological and hydrographic work (2 wet, one of them with circulating seawater, and 2 dry), a diving room, and a workshop. Twelve persons (5 Argentineans, 5 Germans, and 2 Dutch) can be housed in three dormitories. Usually, a total of 24 scientists work at the lab during the entire spring and summer period. Work at sea is currently done by inflatable boats which allow research operations within Potter Cove and in the surrounding area. With the use of the planned launch, field work could be extended to Maxwell Bay.
Field work in Potter Cove is mainly carried out during spring and summer, but some sampling is continued by Argentinean personnel during the winter.

The principal goal of research undertaken at the Dallmann laboratory is to do shallow-water investigations, including the land-sea interface, in a cooperative framework. Jubany is one of the core stations of SCAR's EASIZ programme which studies the ecology and physiology of organisms living in the Antarctic pack ice zone. All data assembled in this context also serve the purpose of modelling the Potter Cove ecosystem. Some important questions to be answered include, (1) How do Antarctic organisms adapt to low-light and low-food winter conditions? (2) What are the main energy fluxes in this shallow-water system, and to what extent do they change seasonally? (3) What are the reactions of this system to disturbance, what is its resilience? (4) In which way does anthropogenic impact modify the structure and dynamics of the coastal ecosystem? (5) What is the effect of climatic variability and change (ENSO, CO_2 increase and global warming, stratospheric O_3 depletion) on shallow-water organisms?

Some of these investigations have been initiated in the past years, others are under way or in a planning stage. This volume is to provide a first account of work done in Potter Cove up to now. It begins with some environmental features to provide an insight into the living conditions, both ashore and in shallow water, in this coastal ecosystem. The main part contains 19 contributions on structure and dynamics of major components of the ecosystem followed by ecophysiological studies on key organisms. The ecophysiological approach is particularly important as it often provides explanations for patterns observed by the ecologists. Both ecology and ecophysiology provide data which can serve as baselines in the case of climatic change. The final part of this compilation includes seven studies on trophic interactions and energy flow, and two studies on anthropogenic impact. To round up the picture, we also include thesis work by young scientists and a series of studies that were carried out by IAA scientists before or outside the Argentinean-German cooperation.

The editors would like to express their thanks to those organisations that have supported scientific-technical cooperation at the first joint laboratory in the Antarctic; in particular, the Ministry of Research (BMBF) and its International Bureau in Germany, the Ministry of Defense and the Secretaría de Ciencia y Tecnología (SECyT) in Argentina, the funding agencies which supported individual projects or persons (Deutsche Forschungsgemeinschaft, CONICET), and the two polar institutes AWI and IAA which provided logistic, material and personnel support. Thanks are also due to Dr. Boris Culik and several colleagues at the AWI and the IAA who acted as referees of the contributions.

The editors would be happy if the Potter Cove study, which will be continued in the next Antarctic season, would become synonymous with the benefits that a joint approach provides for the investigation of Antarctic ecosystems.

Bremerhaven and Buenos Aires, July 1998 The Editors

1. THE ENVIRONMENT OF POTTER COVE

Seismological Observations at Jubany/Dallmann

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Introduction

The South Shetland Islands region is characterized by occurence of earthquakes from small to moderate magnitudes. So earthquakes are mainly recorded on a regional scale and seismotectonic activity is not understood to full extent (Pelayo & Wiens, 1989). During the GAP98 ('Geodetic Antarctic Project 1998') campaign a seismograph system was installed at Jubany/Dallmann Station. The intention is to retrieve in addition to the geodetic measurements further informations from seismological observations about geodynamic parameters in this region. In detail, it is of interest to investigate following items:

- The observation of seismicity in the Bransfield Strait/South Shetland Islands region and depth distribution of epicenters may contribute to a better understanding of the activity of the Bransfield Rift and subduction of Phoenix Plate.
- Together with earthquake recordings from other temporary and permanent stations in this region earthquake focal mechanisms can be determined. From these focal mechanisms deformation directions can be deduced.
- From recordings of teleseismic S-waves a possible seismic anisotropy in the upper mantle below the station can be observed. Seismic anisotropy is generated by recent and fossile deformations in the upper mantle (e.g. Silver, 1996).

Instrumentation, Installation and Operation

The seismic sensor installed at Jubany/Dallmann is a Lennartz LE-3D/20sec 3-component sensor. This instrument is a velocity sensor with an eigenperiod of 20sec with a flat transfer function to frequencies larger than 50Hz. This allows the recording of high frequency local seismicity as well as teleseismic body waves and longperiod surface waves. For data acquisition a REFTEK 72A-07/DAT system is used. This standard seismic acquisition system uses an integrated DAT-tape drive for data storage. Exact time keeping is guaranteed by an integrated GPS time signal

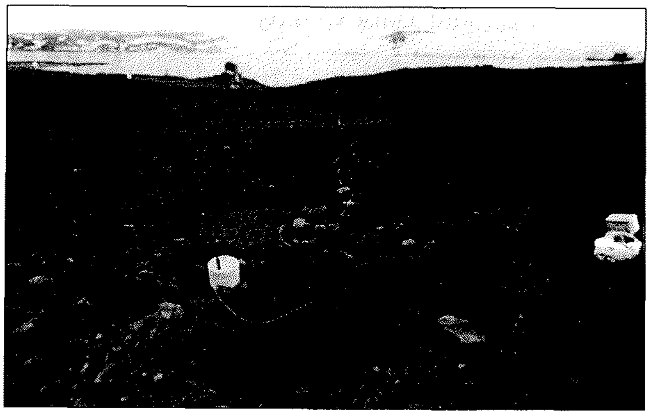

Figure 1: Seismometer before installing in the seismometer fault. In the background the 'Casa Laboratorio' can be seen which houses the acquisition system. The view direction is north-westwards.

receiver. Programming, communication and operation control is possible with an EPSON EHT-10 handheld terminal.

The REFTEK acquisition system is situated in the most easterly building of the Jubany/Dallmann Station complex, called 'Casa Laboratorio'. Power supply for the REFTEK and seismometer is provided by a normal 12V rechargeable battery which is permanently charged from the stations mains. To prevent the recording of station induced noise, the seismometer was buried about 200m away from the 'Casa Laboratorio' in south-easterly direction (Fig. 1). The seismograph system was operational on January 17th 1998.

The coordinates of the seismometer are

$$62^\circ\ 14'\ 13''\ S \quad 58^\circ\ 39'\ 48''\ W \qquad \text{at appr. 20m height.}$$

The acquisition system is configured for a continuous data stream with a sampling rate of 40Hz for all three components (vertical, NS- and EW-horizontal components). With this configuration DAT-tapes must be changed about every three weeks which should be the only maintenance duty of the operator.

During installation the laying of the cable between acquisition system and sensor was problematically because it had to cross a roadway. The problem seemed to be solved by laying the cable inside a metallic pipe which was buried across the road. Nevertheless the cable was damaged by a vehicle which did not exactely use the roadway after eleven days of operation (January 28th). The cable could be fixed on February 14th and was now layed using an overpass to cross the road.

Examples of Recordings and Data Quality

Due to the damaging of the sensor cable only the first eleven days of recording could be analyzed up to now. Due to the open sea the records are characterized by a high noise level in the frequency range below 1Hz. Figure 2 (top) shows a record of 30min duration for the vertical component. No distinct seismic event can be found in this section. The spectrogram in the middle of Fig. 2 shows the spectral power according to time, dark grey means high, light low power. Clearly the high noise around 1Hz can be seen but also distinct lines with high power at higher frequencies. The filtered trace at the bottom shows some seismic events related to these lines of high frequency. Four of them could be related to regional earthquakes from waveform characteristics, others to icequakes which occur frequently from the nearby glaciers.

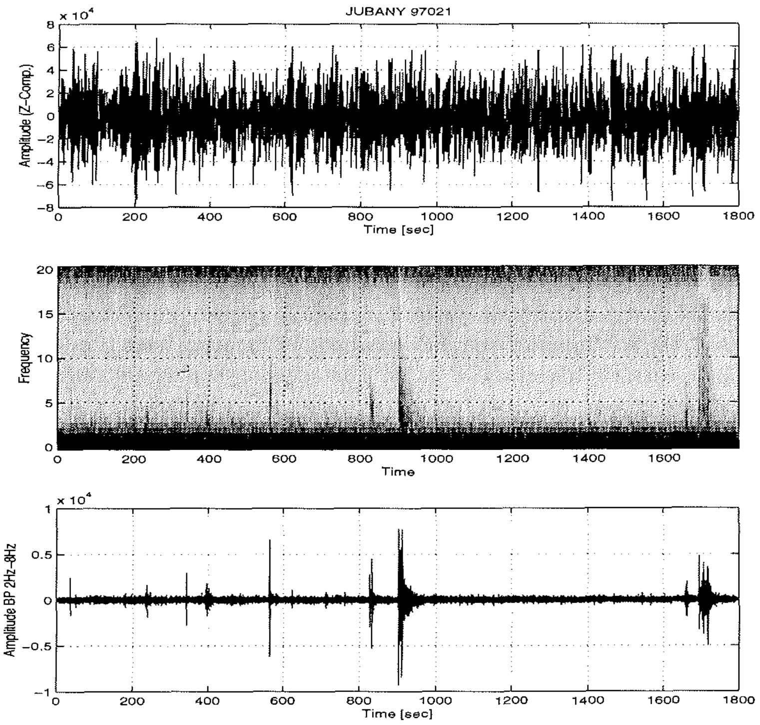

Figure 2: Vertical component record of 30min duration. Top: Original record. Middle: Spectrogram. Bottom: Filtered record (Butterworth bandpass 2Hz – 8Hz).

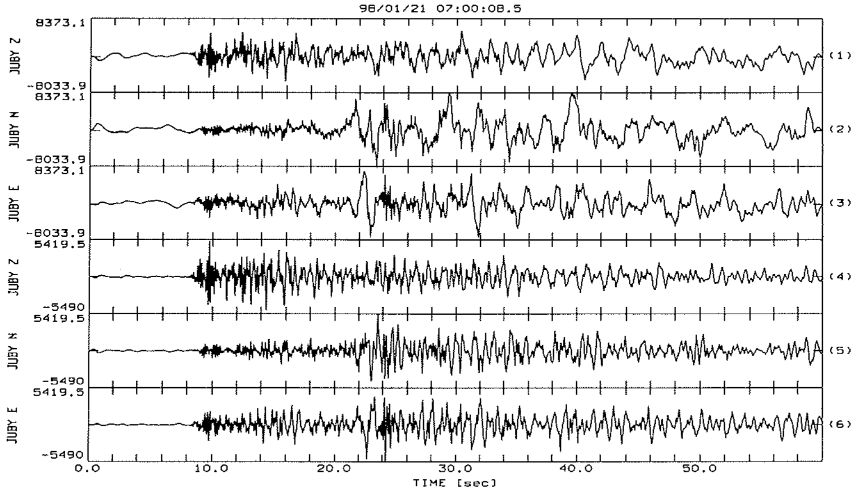

Figure 3: Recording of a local event which occured on 98/01/21. The three top traces show original channels vertical, NS- and EW-components, respectively, traces 4, 5 and 6 same channels but filtered by a Butterworth bandpass (2Hz - 8Hz) filter.

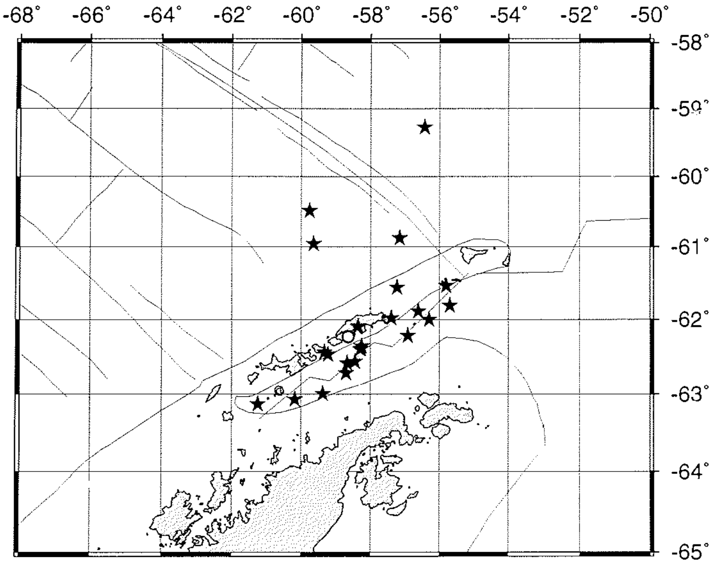

Figure 4: Locations of earthquake epicenters detected during the first eleven days of operation of the Jubany seismograph system.

Figure 3 shows the recording of a typical regional event. The first three channels show the unfiltered recordings for vertical, horizontal NS- and EW-components and channels 4, 5 and 6 the filtered traces with a Butterworth bandpass filter around 2Hz - 8Hz. Clearly the onset of P- and S-phases after 8sec and 21sec can be seen.

In the first eleven days of recording 23 regional events could be found. The localizations from a rough estimation of azimuths from horizontal P-polarizations and distances from S-P traveltime differences is shown in Figure 4. Most of the observed events are located on the assumed rift system of the Bransfield Strait. The few analyzed days of recording yielded a not expected high amount of local/regional earthquakes.

The German part of the research project is supported by the German Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie under the grant 03PL022G.

References

Pelayo AM & Wiens DA 1989. *Seismotectonics and relative plate motions in the Scotia Sea Region*, J. Geophys. Res., 94(86): 7293 - 7320.

Silver PG 1996. *Seismic anisotropy beneath the continents: Probing the depths of geology*, Annu. Rev. Earth Planet. Sci., 24: 385 - 432.

GPS Observations at Jubany/Dallmann

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From repeated GPS observations linked to a global geodetic network, tectonic movements rates can be determined to fit the Antarctic plate into the global puzzle of plate kinematics (Dietrich, 1996). In the frame of the "Geodetic Antarctic Project" (GAP), GPS observations were repeatedly performed in three Epoch Campaigns 1995, 1996 and 1998.

Determining the regional crustal deformation in the area of the South Shetland Islands, the Bransfield Strait and the Antarctic Peninsula is of high geoscientific interest. As a contribution to the study of regional plate movements a permanent GPS tracking station at Jubany/Dallmann was established in 1997. This station is a good supplement to the existing IGS (International GPS Service for Geodynamics) station at O'Higgins. Combining this data with the data from other IGS stations at Santiago (Chile), Hartebeesthoek (South Africa) and Palmer (U.S.A.) a reliable determination of the rifting process of the Bransfield Strait as well as special ionospheric studies will be possible.

GPS Measurements during the Epoch Campaigns

During the SCAR GPS Campaign in 1995 a new GPS point (DAL1) was established at Jubany/Dallmann.

The GPS measurements were made with Trimble SSE (1995/96) and Trimble SSi (1998) receivers (Fig. 3). Connected to the receiver was a L1/L2 Geodetic Antenna (dual-frequency) with a permanently attached groundplane. Figure 2 shows the GPS antenna and a tent which protects the receiver electronic. The permanent marking of the GPS survey point was done with a central marker and three witness points in a distance between 10 to 30 m from "DAL1". The center bench mark consists of a brass cylinder, which is fixed on bedrock. It is possible to screw a tribrach with a adapter and the GPS antenna directly on the marker. The top of the marker has the inscription "GAP 1995" and is covered by a cylindrical cover brass plate. The geodetic reference point is located outside the boundary of the SSSI No. 13.

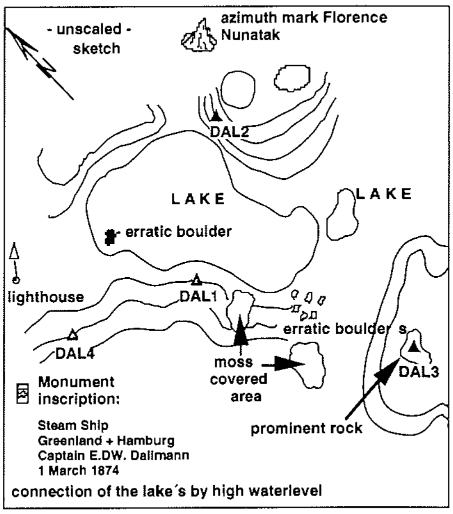

Fig. 1: Unscaled map, showing the location of the center marker "DAL1" with the three witness points

The boundary of the SSSI is defined by a line from the helicopter platform over the Bal Camara (light house) to the "Three Brothers Hill". The marking work was done with care and under arrangement with the station commander from Jubany/Dallmann. The measurements within the local geodetic network (see Fig. 1) was done with four Trimble SSE receivers for one hour with a recording interval of 5 seconds and an elevation mask of 15° for the satellite passes. A geodetic levelling was used to determine the height difference between the three points. Geodetic coordinates defined in the terrestrial reference frame ITRF94 are given below (see table).

Fig. 2: GPS antenna at "DAL1" and tent which protects the receiver electronics

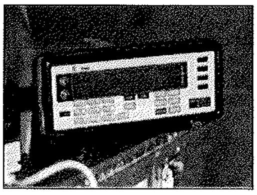

Fig. 3: GPS Receiver Trimble 4000 SSi

Instrumentation and Data Collection of the Permanent GPS Tracker

Since more than one year a permanent GPS Tracker Trimble 4000 SSi (DALL) is in operation at Jubany/Dallmann. An AC-powered Trimble Office Support Module 2 (OSM2) is attached to the PWR - I/O connector. In case of power failure, a battery connected to the receiver is used for power supply. The battery charging output is on PWR 2&3. The receiver electronics are housed in the meteorology shed. A Trimble choke ring antenna with a Dorne-Margolin element is connected to the receiver in order to reduce multipath effects which may be caused by the reflection of satellite signals from the ground. A Trimble conical cover over the antenna prevents snow acommulation, reduces antenna wear, and discourages animals from sitting on it. This radome mounts on a metal plate located under the antenna. A 80 m long of 7/8 inch foam low loss cable connects the GPS antenna to the receiver. The monumentation consists of a concrete pillar which is grounded on a rock outcrop (Fig. 4).

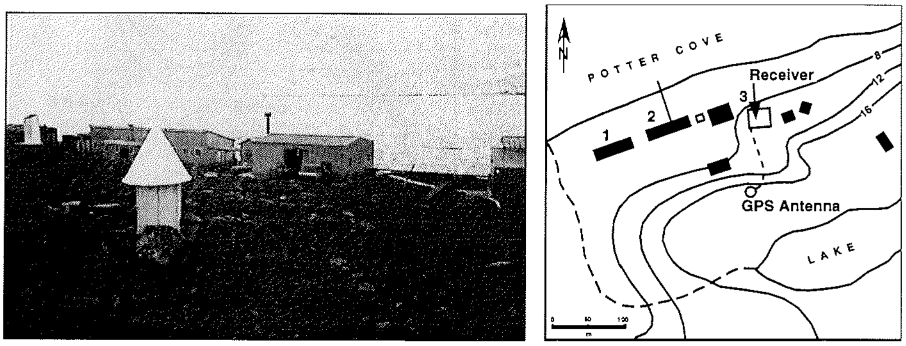

Fig. 4: The left picture shows the GPS antenna and the monumentation at Jubany. The location of the permanent GPS receiver is shown in the map on the right (1: Dallmann Laboratory, 2: Main Building "Casa Principal", 3: Meteorology Shed).

The GPS system was installed on March 5, 1997, and is operated as a stand-alone-system during the Antarctic winter. In operation, the GPS receivers are programmed to track up to a maximum of twelve visible GPS satellites above 10° elevation angle with an recording interval of 15-s. Once a day, a program on a PC establishes a data link to the receiver, downloads the previous 24 h of data and deletes the file on the receiver. After retrieval, the data file is compressed and transferred to an archivel directory on the PC. A data transfer for the post processing in Germany is only possible during the Antarctic summer season. Currently, the recorded GPS measurements of 1997 are processed.

GPS Processing

The data obtained during the SCAR GPS Campaings are analyzed at AWI using GAMIT (GPS at MIT) and GLOBK (Global Kalman Filter VLBI and GPS Analysis Program) software (Pohl and Schenke, 1996). These GPS analysis packages were developed at the Massachusetts Institute of Technology (MIT) and Scripps Institution of Oceanography (SIO) and are used, for example, for automated data analysis in the IGS.

Fig. 5 illustrates the weighted root mean square (WRMS) scatter of the daily position time series for the north, east and up component from the multisession analysis for "DALL". The scatter in the north component is 6 mm and in the east component 7 mm. The up component is significant larger and is about 17 mm.

For "DAL1" and "DALL" the accuracy for horizontal position components is about 1 cm and for the height component in the order of 2 cm.

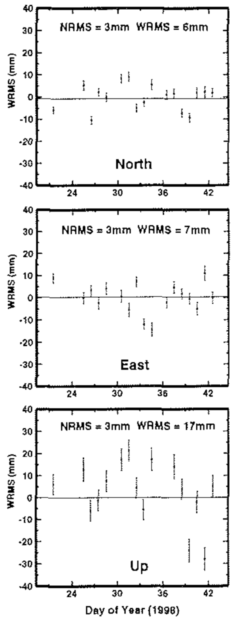

Fig. 5: WRMS scatter of "DALL" station components north, east and up resulting from the multistation / multisession analysis 1998.

Table: ITRF94 coordinates of "DAL1" (GAP95) and "DALL" (GAP98-AWI) in respect to the WGS84 ellipsoid

Marker	Latitude	Longitute	Height
DAL1	62° 14' 26.571" S	58° 40' 40.051" W	41.20 m
DALL	62° 14' 16.334" S	58° 39' 52.363" W	39.40 m

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References

Dietrich, R. (ed.): The Geodetic Antarctic Project GAP95, German Contributions to the SCAR 95 Epoch Campaign. Deutsche Geodätische Kommision, Reihe B, No. 304, München, 1996.

Pohl, M., H.W. Schenke: Precise Baseline Determination using GAMIT/GLOBK Software, in: Dietrich, R. (ed): The Geodetic Antarctic Project GAP95 - German Contributions to the SCAR 95 GPS Epoch Campaign. Deutsche Geodätische Kommision, Reihe B, No. 304, München, 1996, p. 29-36.

Tide Gauge Measurements - A Contribution for the Long Term Monitoring of the Sea Level

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Introduction

In close co-operation with the Instituto Antártico Argentino, Jubany/Dallmann is widely used for geoscientific studies. Due to the operation of the station the year around and its geographical location, at Jubany/Dallmann permanent GPS observations, tide gauge measurements and seismological studies are carried out. With the establishment of an absolute gravity point in 1998, the station will also serve as a basis for relative gravity measurements and related studies in this area, e.g. for studies of the uplift as an effect of glacial rebound.

During the SCAR GPS campaign in 1995, a tide gauge station was deployed for studying mean sea level variations and ocean loadings (Schöne et al., 1996). The sensor was recovered at the end of the campaign. Based on the experience of the '95 campaign, a long term tide gauge was deployed in 1996/97. In 1998 the old tide gauge was replaced to continue the high quality measurements.

Technical design

The most severe problem for the tide gauge station is the freezing and melting of the sea water in winter. Due to the grounding or stranding of ice-bergs, the sensor may be destroyed. Moreover, if the sensor is displaced by ice-bergs a precise determination of sea level changes would not be possible.

For Jubany/Dallmann a special design for the sensor fixing was developed. The tide gauge sensor itself is fitted to a ground plate. To protect the sensor against ice-bergs an iron frame is welded to the ground plate (Fig. 1). A data cable connects the sensor with a scanning and storing unit a shore. In 1995 this cable was cut by a larger ice-berg during our initial observation period. For the new design, a special hose with steel wires is fitted to the data cable. The special set-up makes sure, that the sensor can also operate during winter time.

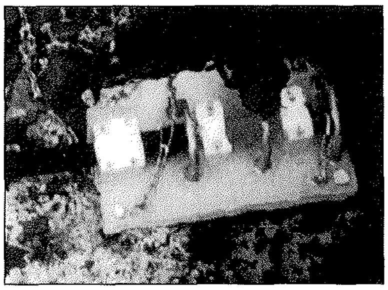

Fig. 1: Example for the fitting of the tide gauge sensor. The ground plate and the steel frame is clearly visible.

In winter 1997, the water column was totally frozen. Therefore, the sensor didn't record for almost one month. After the melting of the ice the sensor continues the operation. But due to the freezing, the sensor may have been displaced and/or destroyed. Therefore, the tide gauge sensor was replaced in order to continue the operation.

Results

Until now two time series of tide gauge records exist for our studies. The first record spans the period 02/96 to 12/96, the second record span 03/97 to 12/97. A harmonic analysis for the partial constituents was performed using the SLPRC software (Caldwell, 1992) of the University of Hawaii Sea Level Center. The amplitudes and phases of both data sets are in good agreement (Tab. 2). The tidal form factor for Jubany/Dallmann is 0.8. Tides are described as mixed, predominantly semidiurnal with this value. The amplitude of the mean spring tide is 148 cm, the amplitude of the mean neap tide is 120 cm.

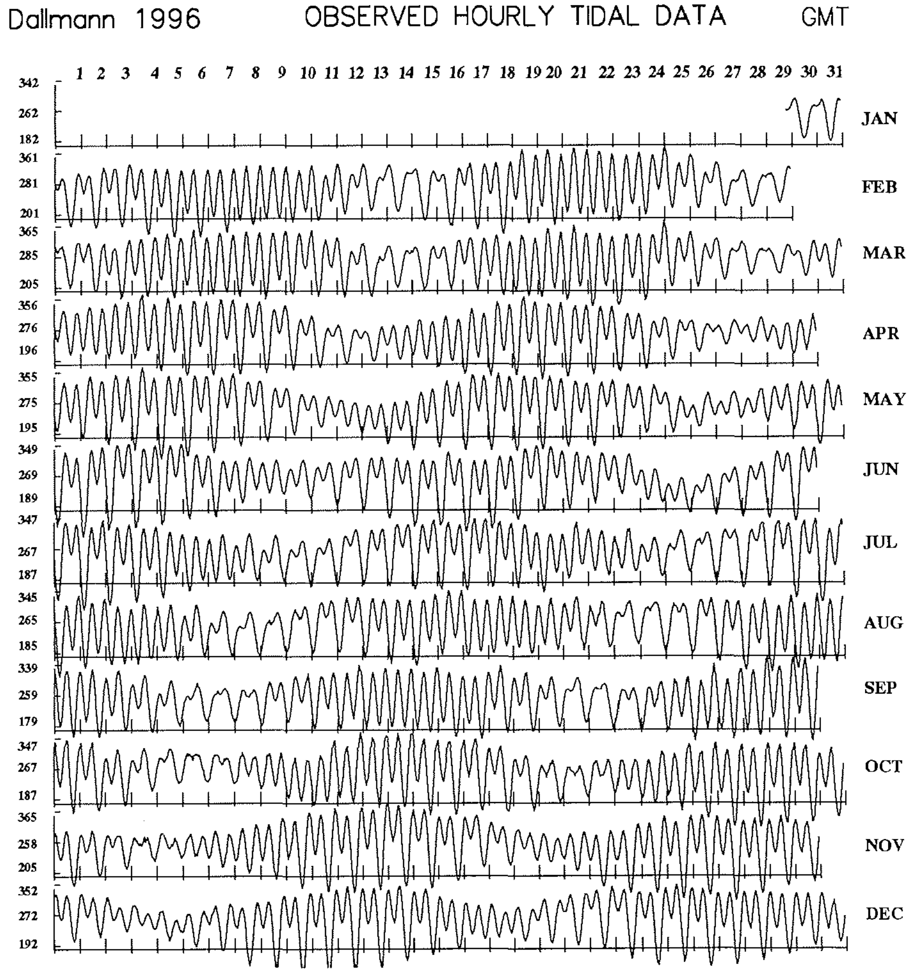

Fig. 2: The Jubany/Dallmann tide gauge record for 1996. The sensor was installed in January 1996. The record has no interruption also in winter time.

It is also interesting to note, that the ice cap formed in winter has almost no effect on the amplitudes of the sea level record. To study this effect in more detail, the tide gauge record was splitted into two sections. Each section spans three month. The "summer section" is February to April (1), the "winter section" is September to November (2). The main harmonic constants are almost in the same range for both data sets (Tab. 1).

	Amplitude (1)	Phase (1)	Amplitude (2)	Phase (2)
O1	30.9	44.1	30.0	44.0
K1	25.4	46.7	22.6	62.8
M2	48.3	275.1	47.4	280.2
S2	29.2	318.0	30.5	334.8

Tab. 1: Comparison for the main partial constituents (amplitude in [cm], Greenwich-phase in [°]) for a "summer period" and a "winter period"

	1996 / Amplitude	1996 / Phase	1997 / Amplitude	1997 / Phase
M2	47.7	277.3	46.3	278.6
O1	30.4	44.3	29.8	44.8
K1	29.4	60.0	28.5	60.1
S2	26.1	328.7	25.1	330.9
P1	9.7	59.6	9.4	60.7
K2	7.5	332.1	6.9	336.4
Q1	7.3	33.3	6.9	35.3
N2	6.4	250.2	5.9	253.0
MF	4.4	207.2	1.9	175.2
MM	3.9	236.2	1.7	227.4
SSA	3.5	55.4	7.0	335.2
MSM	1.1	63.4	3.0	55.9

Tab. 2: Comparison of the partial constituents (Amplitude > 2 cm) for 1996 and 1997 (amplitude in [cm], Greenwich-phase in [°])

The tide gauge recordings were used for a comparison of the mean sea level (m.s.l.) with global geoid models (Schöne et al., 1997). Information about the geoid are necessary to convert ellipsoidal heights derived from measurements with the Global Positioning System (GPS) to orthometric heights used in geoscientific interpretation. Unfortunately, in Antarctica the global geoid models are of limited use. Due to the missing gravity data, the models have larger errors in Antarctica. To derive a unified height system, the m.s.l. derived from our tide gauge record can be used. The difference of the computed m.s.l. to the geoid model OSU91A is 0,60 m, while for the EGM96 model, the difference is only 0,17 cm.

References

Schöne, T., A. Orths, H.W. Schenke: Tide Gauge Measurements, a Contribution to the Vertical Datum Unification, in: Dietrich, R. (ed.): The Geodetic Antarctic Project GAP95 - German Contributions to the SCAR 95 GPS Epoch Campaign. Deutsche Geodätische Kommission, Reihe B, No. 304, München, 1996, pp. 121-123

Schöne, T., H.W. Schenke, A. Zakrajsek: Vertical Datum at the Antarctic Peninsula from GPS and Tide Gauge Benchmark Monitoring, EOS, Vol. 78, No. 17, April 29, 1997, Supplement, p.103

Caldwell, P.: Building an archive of tropical sea level data. Earth System Monitor, 3, No. 2, pp. 4-6

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Meteorological Conditions and Snow Cover Dynamics on the Potter Peninsula, King George Island, Antarctica

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Abstract: Duration and extent of snow cover are important factors for the ecology of peripheral Antarctic habitats. Especially the ice-free areas of the South Shetland Islands are eminent places for the Antarctic flora and fauna. The growth of lichens and mosses as well as the start of the breeding season and the successful rearing is correlated to the snow cover dynamic. We started our investigations on snow cover dynamics in 1992. A ground truth campaign was undertaken to observe the melting process on Potter Peninsula (King George Island, South Shetland Islands). During a two month expedition, we analyzed the snow metamorphosis in several snow pits and measured the and snow depth on a daily basis. Additionally meteorological data were collected to link the ablation process with the energy input from the atmosphere. The point measurements were extrapolated using panchromatic remote sensing data from SPOT satellite with a spatial resolution of 10 x 10 meter. The combination of ground measurements and remote sensing imagery facilitate the derivation of the typical snow cover dynamic for maritime dominated areas of the Antarctic peninsula.

1. Introduction

It is obvious, that accumulation, transformation and melting of snow cover are important processes for the mass balance of glaciers. Snow cover dynamics in ice-free areas is also a very important topic, since periglacial areas are habitats for flora and fauna. This is particularly true for the Antarctic border, for example on the Antarctic Peninsula snow cover dynamics is worth to be investigated as all life in this region depends on narrow, ice-free coastal strips (FOSTER, 1984; WALTON, 1984; CAMPELL et al. 1987). These areas are partly covered by cryptogamic vegetation such as lichens and mosses as well as grasses. The average length of time of snow cover is an important criterion for the spreading of the lichen formations (KAPPEN, 1993). Specifically, the living conditions of the vegetation on the snow cover ablation and the resulting fresh water supply was studied in ice-free areas (ELLIS-EVANS et al., 1990).

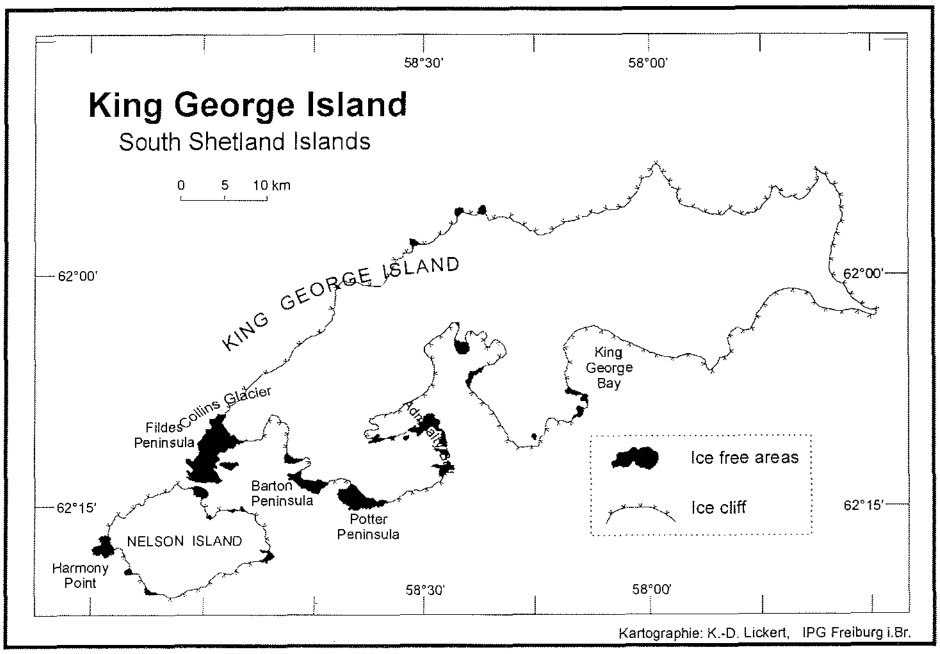
The intensive snowmelt in the northern region of the peninsula and in the coastal areas of King George Island causes the formation of broad wet zones and linear runoff that deeply dissects the loose moraine material and transports a substantial volume of fines to the coastal waters (FLÜGEL, 1990). The knowledge of the amount of meltwater and the time of the runoff into coastal shallow waters are also important criteria for plant physiological studies. Due to the sediment load of the surface water a major portion of short wave radiation is absorbed. In comparison with an equivalent undisturbed area only 0.2 per cent of the available energy reaches a depth of 40 meter in the water column. As a result of the suspended sediment the short wave radiation penetration depth is reduced to 5 meter (KLÖSER et al., 1994). This leads to severely limited growth conditions in near-coastal shallow water regions.

On land after the penetration of the melting front into the ground, solifluidal processes become effective (BARSCH et al. 1984). But the fauna and especially the flora depend on stable soil and, therefore, the habitable area is reduced additionally. Biological studies carried out from an overall ecological viewpoint must take into consideration the yearly snow cover cycle.

In November and December of 1992, a field campaign was carried out on the Potter Peninsula, King George Island, with the primary goal of evaluating the suitability of radar data to determine snow cover characteristics. The results of this campaign with respect to the above described situation are presented here. Additionally, the analysis of optical remote sensing data plays an important role, as sediment streams from snowmelt are readily visible and provide a measure of the intensity of snowmelt (WUNDERLE, 1996).

2. The Research Area

The area investigated is the Potter Peninsula at the southern tip of King George Island, the largest island of the South Shetland group. These islands are described in great detail (BARSCH, et al.,1984; CURL, 1980; MÄUSBACHER, 1991) and we would refer to the authors mentioned above.



Kartographie: K.-D. Lickert, IPG Freiburg i.Br.

Fig. 1: King George Island and Nelson Island (South Shetland Islands) with Maxwell and Admiralty Bay. The largest ice-free areas of King George Island are Fildes Peninsula, Barton Peninsula and Potter Peninsula.

Approximately 95 per cent of King George Island is covered by a radial flowing ice-cap. Tall ice cliffs, for example in the Potter Bay, define the ice-sea interface. The largest ice-free area is represented by the Fildes Peninsula, followed by smaller peninsulas in Maxwell Bay (Barton and Potter Peninsula) as well as in Admiralty Bay.

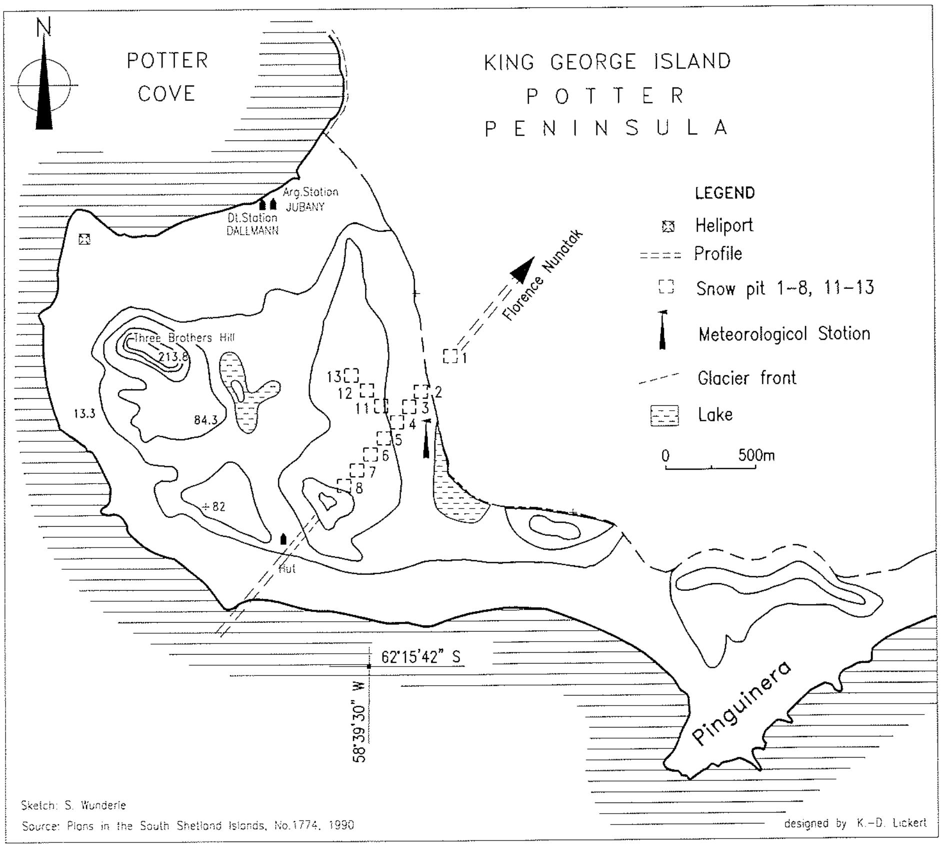


Fig. 2: The Potter Peninsula, King George Island, showing the locations of snow profile and meteorological stations in November, 1992, to February, 1993. The two lakes at the foot of Three Brothers Hill and on the ice margin are primarily fed from snowmelt.

The Potter Peninsula is covered entirely with fluvial dissected moraines of varying age. The blocky material produced through congelifraction at the foot of the Three Brothers Hill (Fig. 2) is mainly the result of weathered and broken hexagonal basalt columns. On the dry relief, which has been ice-free for several hundred years, (CURL, 1980) exists a near completely closed growth of lichens (*Usnea aurantiaco-atra* and *Usnea antarctica*). The stands of growth on the sloping surfaces are in certain areas *en masse* disturbed through cryoturbation and solifluction. West of the ice edge an approximately 300 m wide strip free of vegetation is located. The area is slightly superimposed by periglacial forms with the exception of intensive congelifraction at some places. Up to 4 m deep erosion gullies run from the middle of the peninsula parallel to the ice margin into Potter Bay.

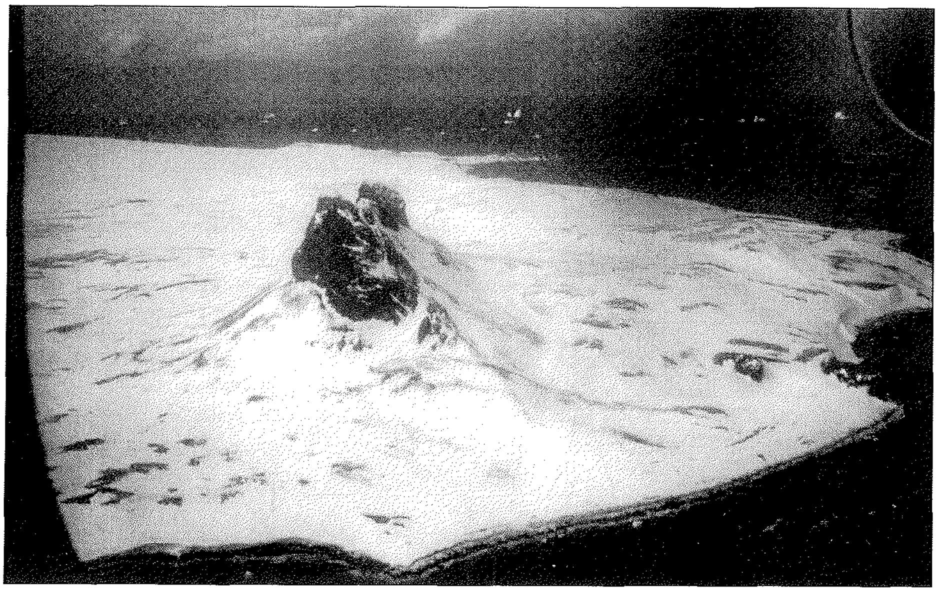


Fig. 3: Aerial photo of Potter Peninsula taken at November 3, 1992. The picture shows Three Brothers Hill and Fourcade glacier (upper left part). The area is almost covered with snow, only Three Brothers Hill and small parts of the moraines are visible.

During the snowmelt, a substantial amount of fine material is transported into the Potter Bay through the gullies. This material builds an alluvial fan and leads to opaque conditions in the water. The east side of Potter Bay is defined by an approximately 50 meter high ice cliff.

A small stripe of the steep ice-free beaches of the north coast are visible during low tide. In contrast to that the south and west coasts are flat beaches with numerous rocks and several cliffs.
Behind the south coast beachwall lagoons on different terrace levels have developed, being mainly fed from streams from the south. Because stream profiles are not fully developed and the loose moraine material is still partially frozen during the snowmelt season many closed, waterfilled depressions and sinks have developed in the hilly region.
Two permanent lakes exists, one at the edge of the glacier and one at the base of Three Brothers Hill. The vast lake located at the edge of the glacier has an extension of 73,000 m^2 and a depth up to 6.5 meter (DRAGO,1983).

3. Climate of the Study Area

The 1992 air temperature measured at the meteorological station of base Jubany shows the typical behavior of a maritime climate in the westwind belt (fig. 4). During the warmest months (December and January), the air temperature varies mainly between 0° and 5° C, but is interrupted by short phases where the temperature dropped below 0° C.
Two extended cold periods occurred in May and June/July causing a decrease in air temperature of approximately -15° C. Also worth noting is that the air tem-

perature can exceed the 0°C level even in the coldest months. The maritime influence moderates the climate, shown through small day/night temperature differences and moderate winters. The annual mean temperature of the coldest month is just below -5° C.

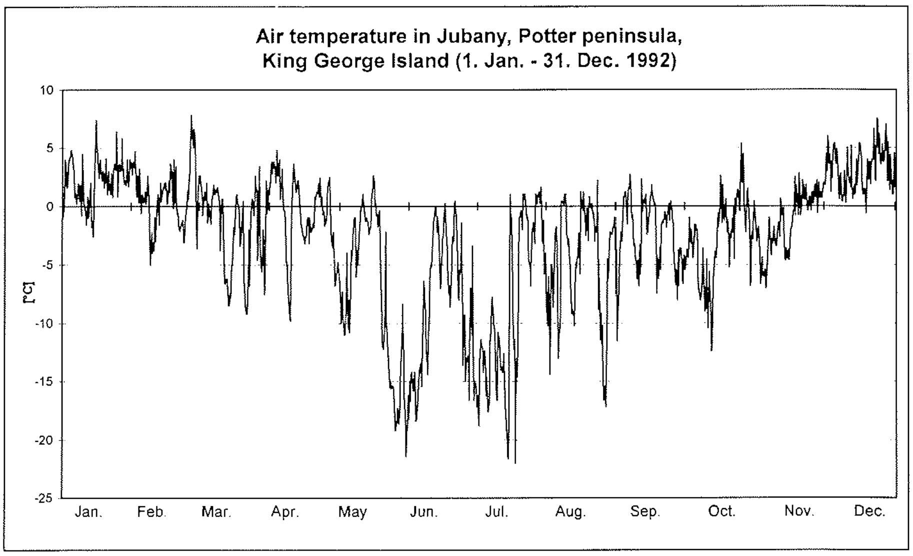


Fig. 4: Air temperature in 1992, measured at the station at Jubany. Even during the winter months, temperatures above 0°C were recorded, which may lead to snow melt. The field campaign took place from the beginning of November until the middle of December 1992.

The annual mean air temperature of -2.7° C and the increase of the air temperature above the 0°C level throughout the year leads to a snow temperature of approximately 0°C at all depths. This acclerates snow metamorphosis and significantly increases snow grain size. The increase of short-wave radiation in late spring combined with higher air temperature causes an intensive snowmelt. The melt water which percolates in deeper layers fills the pores of the snow clusters. Depending on the weather conditions the melt water displaces the air and over an extended period of time funicular conditions can occur.

4. Ground measurements

After a preliminary study in December 1991, a research expedition was planned for late spring 1992 in close cooperation with the DLR[1], ESA[2], AWI[3] and IAA[4]. The field campaign started on November 7, 1992. To investigate the dynamics of snow parameters we marked 11 places on the Potter Peninsula, where we determined the snow properties in snow pits (fig. 2). Additionally, we installed an automatic weather station (AWS) which measured atmospheric parameters

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[1] Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V.

[2] European Space Agency

[3] Alfred Wegener Institut für Polar- und Meeresforschung

[4] Instituto Antártico Argentino

(wind velocity and direction, air temperature, relative humidity and global radiation) as well as long wave radiation of the snow surface and snow or soil temperature at two depths. The data were stored as 10 and 30 minute means in the memory of the CR10 logger from Campbell Scientific. The snow and soil temperature as well as solar radiation were measured by using parts from Campbell Scientific, too. The wind velocity and direction were measured in 2m height with vector instruments. Data were collected continuously from November 9, 1992, until February 12, 1993. The extended period was due to the maintenance of the AWS by scientists of base Jubany and colleagues from University of Bremen.

At the beginning of the campaign, more than 90 per cent of the surface of the Potter Peninsula were covered with snow of highly varying thickness (see fig. 3). The varying thickness of the snow is caused by high wind velocities (v > 10m/s) in combination with the hummock relief. Strong winds during and after precipitation periods cause an irregular distribution and deposition of new snow layers. On slopes which faces windward the snow becomes heavily windpacked, while on the leeward side large, cornice areas develop. Due to this horizontal redistribution of snow 2 to 3 meter may accumulate in low depressions but only thin sheets of new snow remain in wind exposed areas. Due to high wind velocities and the deflation of the snow surface Sastrugis develop, running parallel to the wind direction. The rough snow surface forces the turbulence and therefore the energy exchange between atmosphere and snow.

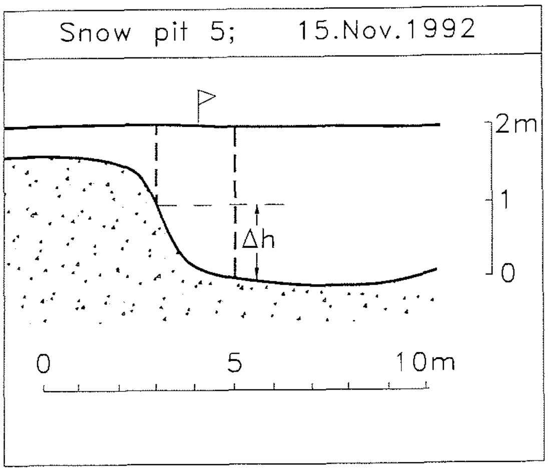

Fig. 5: Snow profile at Station no. 5 on the Potter Peninsula, Nov. 15, 1992. The locally varying relief led to large differences (Δh) between measurements at the snow pits.

The snow pit locations were chosen to give a representative cross section of the study area. The gently rolling, unbroken snow surface made it difficult to discern the underlying topography. Conversely, the local relief variability of the young moraine landscape makes it difficult to estimate the snow cover thickness as a mean for the whole peninsula. As much as 1 meter difference in snow thickness was measured among 10 measurements, which were all undertaken 1 meter from a central point. This fact is reflected in the high standard deviation for snow thickness values. Accurate snow thickness measurements are an important prerequisite in order to document the continuous snow ablation and loss processes.

Table 1: Snow thickness (average, minimum, maximum and standard deviation) for selected test locations of the Potter Peninsula, Nov. 15, 1992 (see Fig. 2).

	Average [m]	Minimum [m]	Maximum [m]	Std. Dev. [m]
Location 1	1,89	1,80	2,02	0,06
Location 4	0,37	0,16	0,55	0,14
Location 5	0,85	0,18	1,53	0,52
Location 6	0,60	0,51	0,75	0,08

An exact analysis of the snow cover formation, i.e. stratification, density, kernel size and amount of ice horizons could be done after in-situ measurements in snow pits. During the campaign at least one and often some snow profiles per marked location were dug. The snow layer, which was subdivided due to several ice horizons and ice lenses, was very coarsely grained. The thickness of the ice layers are between 0,5 and 3 centimeter. The series of layers had a very tight spacing, between 5 and 25 centimeter, all with a density between 400 and 530 kg m^{-3}.

The snow in pit 1, located on the Fourcade glacier tongue (fig.2), was composed of nine distinct strata, which had different snow kernel size bounded by ice layers. The snow kernels had a diameter of approximately 1 mm in the highest stratum and increased to 2 to 3 mm in the lower strata. These exceptionally large kernel diameters resulted from densification processes - especially from a long period of freeze-thaw metamorphosis, which resulted from a snow cover temperature near 0°C.

The snow density measurements taken on ice-free locations were slightly higher than the density values from test point 1. The density attains values between 460 and 580 kg m^{-3}. Remarkable are the diameters of the snow kernel clusters which were found > 5 mm. The growth of several ice horizons in the snowsheet in addition to large snow kernels indicate many freeze-thaw cycles throughout the entire year.

5 Melting of the Snow Cover

From early November through the middle of December, 1992, the snow cover had nearly disappeared.

During the first few days of the campaign, the recorded mean daily air temperature was -5° C, which in the course of the campaign reached approximately +2°C. The measured small variance in temperature and the high values of relative humidity are characteristic for a polar region dominated by oceanic climate.

Table 2: Meteorological parameters from the AWS from November 20 to December 20, 1992. The meteorological station was located near snow pit 4. All parameters were measured in a height of 2m above snow surface / ground. Shown are the average and extreme values during the campaign.

	Average	Maximum	Minimum
Air Temperature [°C]	0,7	8,4	-6,2
Relative Humidity [%]	87,3	98,6	34,5
Wind Speed [m s^{-1}]	7,8	21,3	0
Global Radiation [Wm^{-2}]	202,7	1073	0

In addition to the high values of solar radiation the high air temperatures in combination with the high sensible heat flux produced a reduction of up to 2 m of the snowsheet in less than four weeks. This resulted through melting as well as by snow crystal metamorphosis. Additionally the ablation was accelerated by high wind velocities during November and December, 1992.

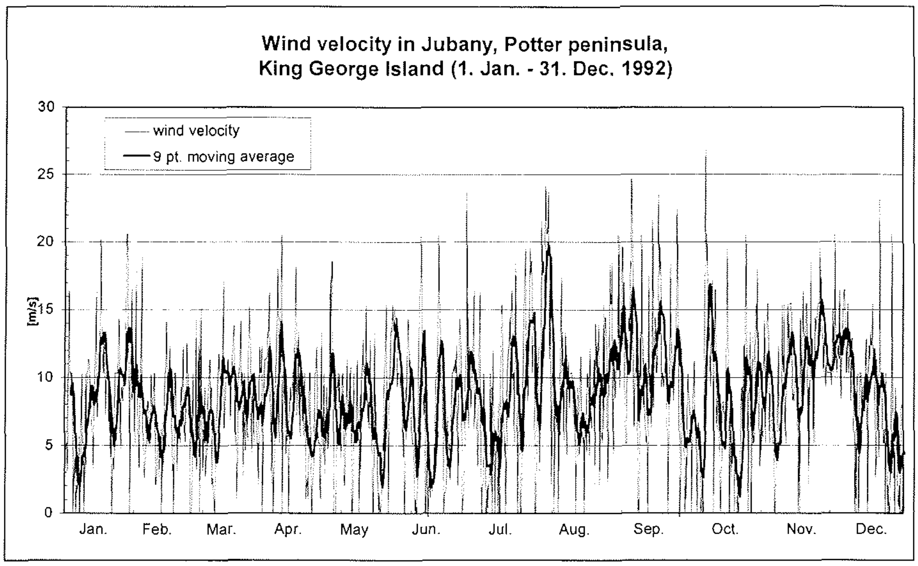

Fig. 7: Wind velocity, 1992, measured at Jubany Station. Remarkably is the high average wind velocity during the field campaign in November / December, 1992.

Average values were just over 8 m/s, with highest velocities above 25 m/s. Calm conditions were rarely recorded. In comparison with former Jubany Station records wind velocity was unusually high, but this does not lead to a principle change in behavior of snow layer ablation compared to other, less windy years. The most common wind directions cover the sector from 270° to 315°.

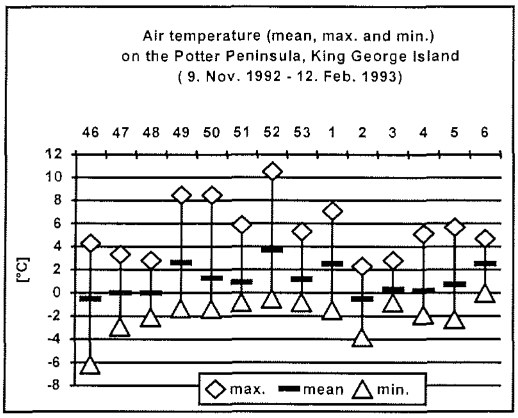

Fig. 8: The air temperature on Potter Peninsula, taken at the meteorological station near snow pit 4. The weekly average varies between 0°C and +4°C. During the middle of December, 1992, a maximum value above +10° C was recorded.

On days with full cloudcover, global radiation was measured at approximately 300 Wm^{-2}, whereas up to 860 Wm^{-2} were measured on clear days during the summer solstice. At the beginning of the campaign, when the test area was covered nearly completely with a snow cover a 10 min.-mean of 1073 Wm^{-2} was recorded under partly cloudy conditions. The reason for this high value was multiple reflection of the short wave radiation between the snow surface and the bottom of the cloud layer. The maximum value during the sunny days in November were 780 Wm^{-2}. On December 21, 860 Wm^{-2} were recorded. Approximately 20 per cent of the short wave radiation was absorbed by the atmosphere due to the low sun angle and high water vapor values.

The short-wave radiation from November to December leads to a fast warming of the near-ground air layer, resulting in an increasing melting rate and a significant temperature increase of the darker ground material. In less than 60 days the snow cover, in places 3 m thick, disappeared and caused high discharge additionally increased by rain. The snow cover reduced vertically and its horizontal dimension also noticeably shrank. The moraine material was heated by the daily cycle of global radiation. The ground temperature is dependent on the ground cover type, the water content and the covering of plants or snow. The temperature of snow covered ground reached 0°C during the day and decreased to -1°C at night.

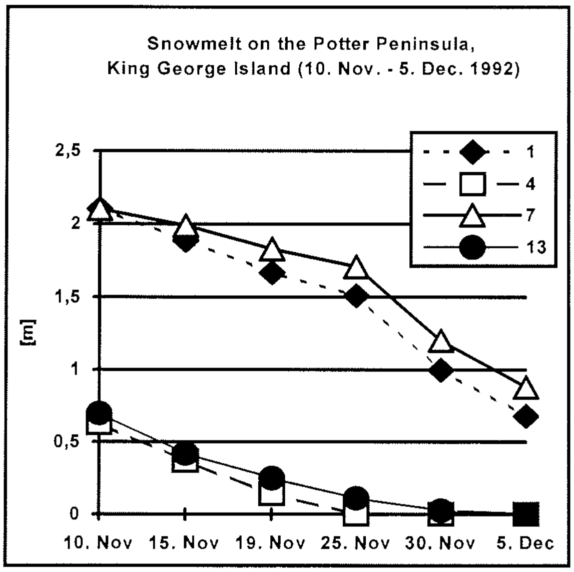

Fig. 9: Ablation of the snow cover on the Potter Peninsula, King George Island, at snow pits no. 1, 4, 7 and 13 (fig. 2). During a three week period, the snow depth decreases 1.5 m. Between November 25 and 30 high energy input of sensible heat flux due to a patchy snow cover caused a rapid decrease of the snow layer.

After melting of the snow cover, the top centimeters of the ground were water saturated, resulting in maximum average ground temperatures of only +5°C. The heating of the ground led to a lowering of the 0°C isotherm into deeper layers as well as a melting of ground ice. This process causes a shift of the local water divide of the moraines in deeper levels. The small lakes formed during the melt period could drain through the loose moraine material.

As the upper centimeters of the ground went dry, the average maximum temperature of the ground increased to +11°C with a maximum of +16°C at noon. The dark, igneous congelifracts of the surface absorbed the solar radiation. Due to the strong winds during the ablation period, horizontal advection of sensible heat were transferred from the warm ground to the snow covered regions.

This sensible heat flux considerably accelerated the ablation process. During the first weeks of December, slush flows over large areas of the Fourcade glacier tongue occurred frequently, revealing the glacial ice. By the middle of December, 1992, the Potter Peninsula was predominantly snow free and the impounded water regions were reduced to two large lakes, one at the ice edge and the other at the foot of Three Brothers Hill.

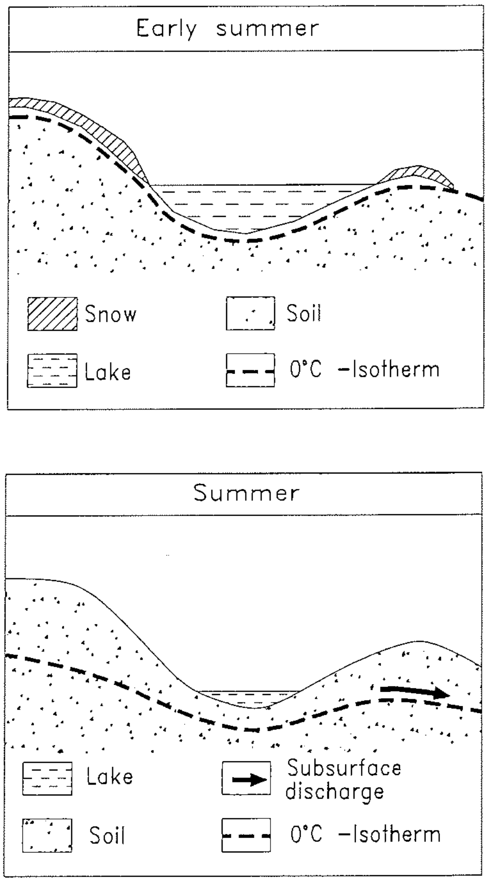

Fig. 10: Diagram of the lowering of the 0°C isotherm. After snow cover melt, the ground warms and the impounded water is able to drain through the loose moraine material.

6 Documentation of the Ablation Process by Means of Remote Sensing Data

In advance of the 1992-expedition to King George Island, we put an acquisition order to SPOT-Imáges with the aim to receive some panchromatic images of our test area. Three almost cloud free images from November 3, 18 and December 21, 1992, were received. The images with a spatial resolution of 10 x 10 m^2 were superimposed and unsupervised classified.
Due to the difference in reflectivity between soil and snow, the snow patches are clear to distinguish. The result of the classification (see fig. 11) shows the dynamic of the ablation process on the Potter Peninsula. The snow free areas at November 3, 1992, are visualized in black color (see fig. 3 as comparison). They are located at the Three Brothers Hill and some steep parts at the south coast. During November, the air temperature, the sensible heat flux and the global radiation increased and led to a rapid decrease of the thinly snow covered areas on the top of the moraines.

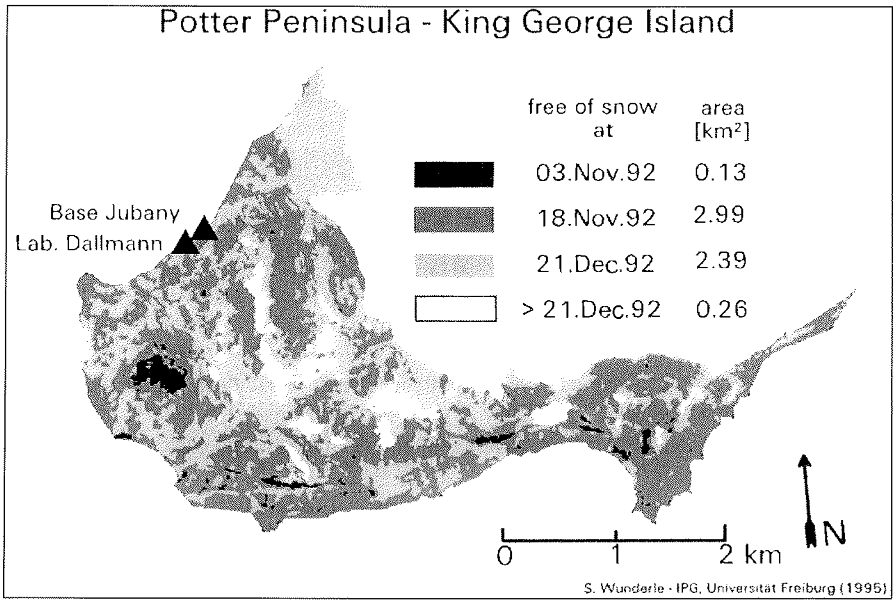

Fig. 11:The ablation process on the Potter peninsula, derived from three panchromatic SPOT-images (November 3, 18 and December 21, 1992). The great difference in reflectivity between snow and soil allows the determination of the snow free areas with a high accuracy. At November 3, only tiny patches (0.13 km^2) are snow free, visualized in black color. Two weeks later, half of the Potter Peninsula is free of snow (3.12 km^2), shown in dark gray. Almost the whole test area is snowless at the 21st of December, 1992 (gray). Only small areas between the moraines remain snow covered.

These areas (almost 3 km^2), shown in gray color represent half of the peninsula which became snow free during a 8-days period. Until December 21, the ablation process on the Potter Peninsula was nearly complete. Only some small patches (0,26 km^2) were still covered with wet, coarse grained snow. Due to the high water content of the snow cover on Fourcade glacier snow slabs slipped down and bare glacier ice was visible.

7. Final comments

The coastal area of the Antarctic peninsula particularly the periglacial areas of King George Island are eminent places for the Antarctic flora and fauna. The whole life is correlated with the snow cover dynamic. Our ground truth campaign with a lot of measurements of the snow cover combined with meteorological data and remote sensing images shows the typical melting process in Antarctic areas dominated by oceanic climate. During a two or three week period in November almost the whole Potter peninsula is free of snow. During this time the melt water runoff deeply dissects the moraine material and transports the fines to the coastal waters. The sediment flow can be detected by using optical remote sensing data (Wunderle et al. 1995).
Due to a warmer climate in the next decades we expect an acceleration of the snow cover dynamic in this region.

8. Literature

Andrade, B. & P. Vicuña (1993): Determinación de Ambiente crio-nival mediante la comparacion estacional des imágenes SPOT en el Litoral Antártico de Isla rey Jorge. - Selper Revista (9), No. 1/2, pp.79-82

Barsch, D. & G. Stäblein (1984): Frostdynamik und Permafrost in eisfreien Gebieten der Antarktischen Halbinsel. - Polarforschung 54, 111-119

Barsch, D. & G. Stäblein (1986): Beiträge zur Vergletscherungsgeschichte und zur Reliefentwicklung der Süd Shetland Inseln. - Z. Geomorph. N. F., Suppl. Bd. 61:25-37, Berlin, Stuttgart

Barsch, D., Blümel, W.D., Flügel, W.A., Mäusbacher, R., Stäblein, G. & W. Zick (1985): Untersuchungen zum periglazial auf der König Georg Insel Südshetland - Antarctica. Bericht über die Kampagne 1983/84. - Berichte zur Polarforschung, 24: 1-75, Bremerhaven

Campbell, I. B. & G. G. C. Claridge (1987): Antarctica: Soils, Weathering Processes and Environment, Developments in Soil Science 16. - Amsterdam, Oxford, New York

Curl, J. E. (1980): A Glacial History of the South Shetland Islands - Antarctica. - Institute of Polar Studies, Ohio, Report No. 63

Drago, E. C.(1983): Estudios Limnologicos en la Peninsula Potter, Isla 25 de Mayo (Shetland del Sur): Morfologia de Ambientes Leniticos. - DNA, Instituto Antartico Argentino. Contribucion No. 265

Ellis-Evans, I. C. & D. W. H. Walton (1990): The process of colonization in Antarctic terrestrial and freshwater ecosystems. - Proc. of the NIPR Symposium on Polar Biology, 3, 151-163

Flügel, W. A. (1990): Water balance and discharge simulation of an oceanic Antarctic catchment on King George Island, Antarctic Peninsula. - Beiträge zur Hydrologie, Jg. 11, 2, 29-52.

Foster, T. (1984): The marine environment. - Antarctic Ecology, Vol. 2, 345-371.

Hochschild, V. (1995): Geomorphologische Kartierung und Untersuchung zur Auftaudynamik mit ERS-1-SAR-Daten im Bereich der Antarktischen Halbinsel. - Bremer Beiträge zur Geographie und Raumplanung, Universität Bremen, Bd. 28, p. 160.

Kappen, L. (1993): Plant activity under snow and ice with particular reference to lichens. - Arctic 46, 297-302

Klöser, H. & W. E. Arntz (1994): RASCALS - Untersuchungen zur Struktur und Dynamik eines antarktischen Küstenökosystems. - Polarforschung 64 (1): 27 -41

Lindsay, D. C. (1971): Vegetation of the South Shetland Islands. -British Antarctic Survey Bulletin, No. 25, 59-83

Mäusbacher, R. (1991): Die jungquartäre Relief- und Klimageschichte im Bereich der Fildeshalbinsel, Süd Shetland Inseln, Antarktis. - Heidelberger Geographische Arbeiten, 89:1-205, Heidelberg

Schulte, A.(1985): Die Entwicklung der Ausaperung über kontinuierlichem Permafrost auf der König Georg Insel, Südshetlands, Antarktis, im Südsommer 1984/85. - Diplomarbeit Universität Heidelberg, 1-79, Heidelberg.

Stäblein, G. (1985): Dynamik und Entwicklung arktischer und antarktischer Küsten. - Kieler Geogr. Schriften, 62: 1-18

Walton, D. W. H. (1984): The Terrestrial Environment. - In: Laws (ed.): Antarctic Ecology, Vol. 1, 1-61.

Wunderle, S. (1996): Die Schneedeckendynamik der Antarktischen Halbinsel und ihre Erfassung mit aktiven und passiven Fernerkundungsverfahren. - Freiburger Geographische Hefte, Bd. 48, p.172

Wunderle, S. & H. Goßmann (1995): Investigacion de la dinamica de la capa de nieve de King George Island y una region costera de Marguerite Bay (Antarctica) por medio de imagenes SPOT y ERS-1. - Revista SELPER, Vol.11, No.1-2, 65-71

Wunderle, S. & H. Saurer (1995): Snow properties of the Antarctic Peninsula derived from ERS-1 SAR images. - Proc. of the 21st Annual Conference of the Remote Sensing Society, 11-14 Sept. 1995, University of Southampton: 1231-1237

Wunderle, S. (ed.) (1997): Proceedings of the EARSeL Workshop Remote Sensing of Land Ice and Snow. University of Freiburg, Germany, 17 - 18 April 1997, pp.135

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Seasonal variation of abiotic factors in terrestrial habitats

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In the maritime Antarctic lichens and mosses form the major component of the flora. Large parts of the ice-free areas are bare of any vegetation, whereas nearby sites are well covered with cryptogamic communities. The distribution of the vegetation and the vegetation pattern is controlled by various environmental factors. Areas that have been uncovered from snow and ice, such as near glaciers or old snow fields are too young to be colonized by cryptogams. Steep slopes, scree and mudd fields remain open because of cryotubation. Snow cover reduces the solar radition, which supplies the energy available for photosynthesis and controls temperature and water regimes in the microclimate of low-growing cryptogamic vegetation (LONGTON 1988) and has a pronounced seasonality in polar regions. But even covered by a snow layer up to 15 cm lichens are able to photosynthesize (KAPPEN & BREUER 1991; KAPPEN et al. 1995). A deeper snow cover protects the underlying vegetation from the effects of low air temperatures (DAVEY et al. 1992) and wind-induced erosion (LONGTON 1988). On the other hand, under a repeated long lasting snow cover snowkill is possible due to neglible light penetration in combination with relatively high temperatures causing destructive respiration (GANNUTZ 1970, BENEDICT 1990). Therefore, seasonal snow cover can be an important factor that limits the development of the vegetation (SELKIRK & SEPPELT 1987, KAPPEN et al. 1990, SMITH 1990).

Only a few long-term studies on the microclimatic conditions for Antarctic cryptogams have been made (FRIEDMANN et al. 1987, 1993, SCHROETER et al.1993, SCHROETER et al.1994, MELICK & SEPPELT 1997). In order to describe the living and growth conditions for lichens and mosses in the area near Jubany Station the microclimate was registered continously along a transect of 15 m length near the coast (Fig 1). The transect runs from the foot of the southern slopes of the basalt hills, Tres Hermanos (214m), where the vegetation pattern is strongly varying. It traverses from a depression with a melt water runnel and a close stand of moss turf to a wind-swept plateau covered with a dense lichen heath. Thallus temperature (TT) and irradiance (measured as photosynthetic photon flux density (PPFD)) of the moss *Sanionia uncinata* in the depression and of the macrolichen *Himantormia lugubris* in the lichen heath were recorded as well as air-temperature (AT) and irradiance approximately 1 m above ground. Data were collected every 30 minutes by a logger (Squirrel, Grant, UK). Temperatures were measured by a mini- and microthermistor probes respectively (Grant, UK) and irradiance at thallus level by a quantum sensor. As the reference sensor for irradiance a spherical quantum sensor (LiCor, USA) was used. Because of the spheric construction also the reflected radiation is registered. Therefore the values of daily PPFD at thallus level are lower than these of the reference sensor. Snow cover and depth were recorded manually with sticks in the transect and/or measured automatically by solidly mounted vertical bars (60 cm long) with infra-red light barriers at every 5 cm (up to 30 cm) or 10 cm (30 to 60 cm) distance from the ground.

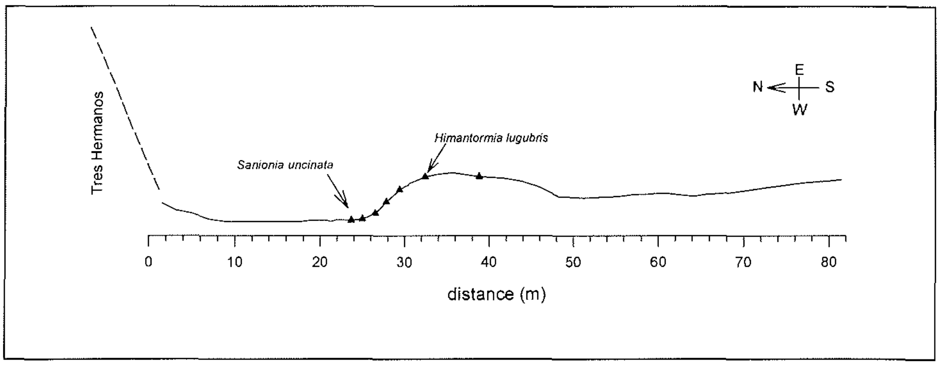

Fig. 1: Sketch map of the transect. Arrows indicate the sites for the microclimatic measurements, and triangles the snow depth sensors.

As a preliminary result the annual course of the microclimatic conditions (TT, AT, PPFD, snow depth) for *Sanionia uncinata* and *Himantormia lugubris* is illustrated in Figs. 2 and 3. Data from December to February describe the situation in the summer season with positive daily mean air temperatures most of the time. The PPFD values indicate that *Sanionia uncinata* was snow-covered until the beginning of December (Fig. 2). A summer snow fall causes snow covering on the moss and thus reduction of PPFD for several days. In contrast the thallus of *Himantormia lugubris* on the more wind-swept plateau was snow-free already by the end of October and the thallus got free of freshly fallen snow always within 1 or 2 days. For both, the lichen and the moss, the light regime was appoximately the same in this time of the year (25 mol m^{-2} d^{-1} mean daily PPFD sum). PPFD for the snow-free cryptogams was about 50-60% of the values registered by the reference sensor (s.a.). On sunny days mean TT within the blackish lichen thallus was clearly higher than mean daily AT (Fig. 3) and maximum temperature could exceed 30°C whereas within the moss mat maximal TT mostly did not reach 20°C. On overcast and rainy days mean TT of *Himantormia lugubris* as well as *Sanionia uncinata* followed the AT curve.

In late summer/autumn PPFD is markedly reduced. Snow fell only few times but covered *Sanionia uncinata* in April for a period of nearly 4 weeks during which TT always were below 0°C but with a low amplitude. The daily PPFD was reduced to values of 0.3 to 0.5 mol m^{-2} d^{-1} PPFD. Like in summer the thallus of *Himantormia lugubris* was snow covered for no more than 2 or 3 days so that the amount of solar radiation reaching the thallus in April was three times higher than that reaching the moss. Mean daily TT of *Himantormia lugubris* was very similar to mean air temperature. Both parameters dropped below 0°C at the end of March but exceeded the freezing point again several times until May.

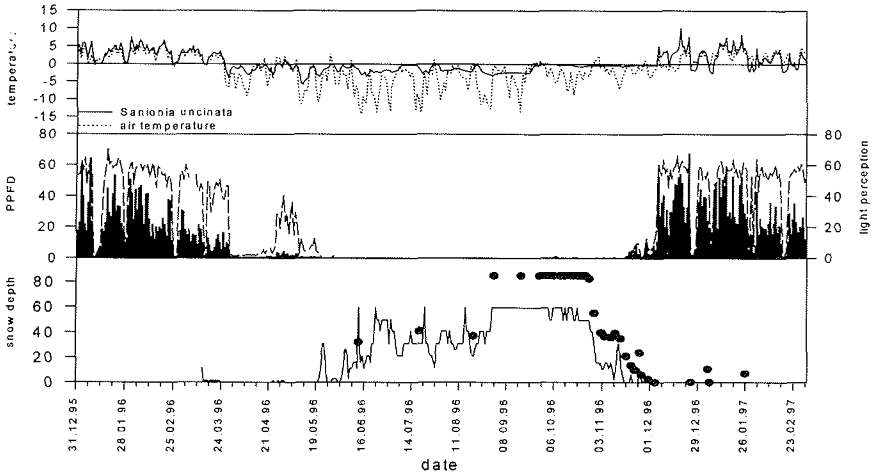

Fig. 2: Annual course of daily mean temperature (°C), daily sum of PPFD (mol m^{-2} d^{-1}), light perception at thallus level (% of ambient light) and snow depth (cm) (the line indicates the automatical measurements and the symbols the manual measurements) in *Sanionia uncinata* in 1996 (Winkler unpublished).

In winter (from June to the end of August) the climatic situation was totally different. Whereas *Sanionia uncinata* was under snow cover deeper than 20 cm from the end of May till the end of August (Fig. 2), the snow layer at the plot with *Himantormia lugubris* maximally amounted to less than 6 cm (Fig. 3). No light reached the thallus of *Sanionia uncinata* from June to October. During this period the daily sum of radiation reaching the lichen thallus was mostly between 0.2 and 0.4 mol m^{-2} d^{-1} PPFD. That means that PPFD maxima were up to 130 µmol m^{-2} s^{-1} PPFD. Due to the snow cover the diel oscillation of TT in the moss mat ceased and even maximum TT never reached the freezing point. In contrast, like the maximal air temperature, maximum TT of *Himantormia lugubris* exceeded 0°C at some days in July and August.

The highest amount of snow in the transect was recorded in September. In the depression where *Sanionia uncinata* is located the snow depth was more than 85 cm the until end of October and snow cover lasted until December. Maximal snow depth for *Himantormia lugubris* was 67 cm on 19 September 1996 but already on 30 September it was reduced to 4 cm. Even if the ground is covered with a thin layer of snow (4-8 cm) light intensity reaching the lichen was strong enough to heat the blackish lichen thallus so that mean daily TT was higher than AT and could exceed the freezing point. Light perception of *Himantormia* *lugubris* in October was between 10 and 20% of the ambient radiation. However, this is not a compelling evidence that the thallus was covered by snow. Because of the spherical construction of the reference sensor and the high reflection by the snow which was patchy in these months, light gain for the thallus would be underestimated. As long as *Sanionia uncinata* was covered with snow the TT matches long-term trends of the mesoclimatic conditions. At the end of September mean daily TT increased to temperatures between -0.1°C and -0.8°C until December although AT stayed cooler most of the time. This increase of TT within the moss mat can be influenced by melt water streams running of from elevated sites beneath the snow. During the whole time of snow pack the daily amplitude of TT in the *Sanionia uncinata* mat did not exceed 0.25 K except once.

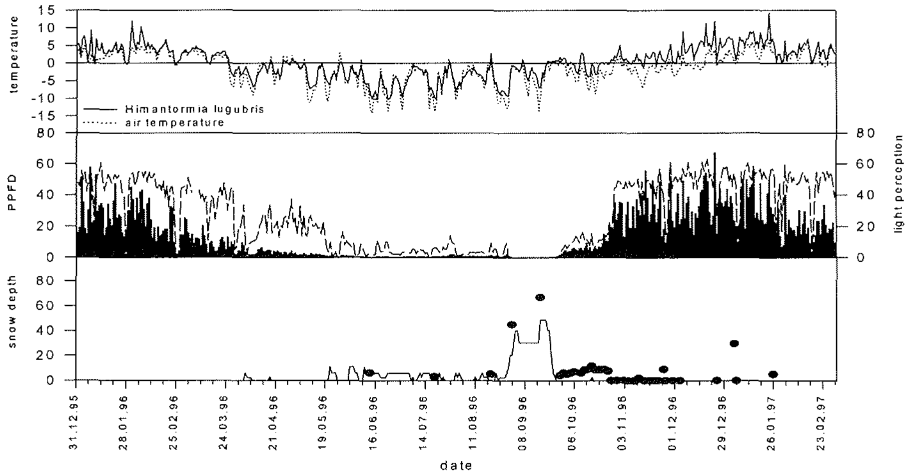

Fig. 3: Annual course of daily mean temperature (°C), daily sum of PPFD (mol m^{-2} d^{-1}), light perception at thallus level (% of ambient light) and snow depth (cm) (the line indicates the automatical measurements and the symbols the manual measurements) in *Himantormia lugubris* in 1996 (Winkler unpublished).

These measurements demonstrate differences between the microclimatic conditions for the cryptogams in the more sheltered depression to these on the wind-swept plateau. In the depression the microclimate characterizes a situation where only bryophytes and a few crustose lichens can exist whereas the microclimatic conditions and snow frequency on the plateau are adverse to bryophytes and allow fruticose lichens to be very competetive. Snow cover and depth influence the temperature as well as the light regime in these habitats. As assumed by KAPPEN & SCHROETER (1997) it seemed as if spring to early summer and fall are the most important periods for the primary production of lichens, when water is available e.g. from melting snow and enough light reaches the thalli to provide photosynthetic activity.

References

BENEDICT, J.B. (1990): Lichen mortality due to late-lying snow: results of a transplant study. Arctic and Alpine Research 22: 81-89.

DAVEY, M.C.; Pickup, J.; Block, W. (1992): Temperature variations and its biological significance in fellfield habitats on a maritime Antarctic island. Antarctic Science 4: 383-388.

FRIEDMANN, E.I.; MCKAY, C.P.; NIENOW, J.A. (1987): The cryptoendolithic microbial environment in the Ross Desert of Antartica: Satellite-transmitted continous nanoclimate data, 1984-1986. Polar Biology 7: 273-287.

FRIEDMANN, E.I.; KAPPEN, L.; MEYER, M.A.; NIENOW, J.A. (1993): Long-term productivity in the cryptoendolithic microbial community of the Ross Desert, Antartica. Microbial Ecology 25: 51-69.

GANNUTZ, T. P. (1970): Photosynthesis and respiration of plants in the Antarctic Peninsula area. Antarctic Journal of the United States 5: 49-52.

KAPPEN, L. & SCHROETER, B. (1997): Activity of lichens under the influence of snow and ice. Proc. NIPR Symp. Polar Biology 10: 163-168.

KAPPEN, L.; MEYER, M.; BÖLTER, M. (1990): Ecological and physiological investigations in continental Antarctic cryptogams. I. Vegetation pattern and its relation to snow cover on a hill near Casey Station, Wilkes Land. Flora 184: 209-220.

KAPPEN, L. SOMMERKORN, M.; SCHROETER, B. (1990): Carbon aquisition and water relations of lichens in polar regions - potentials and limitations. Lichenologist 27: 531-545.

LONGTON, R.E. (1988): Biology of polar bryophytes and lichens. Cambridge University Press, Cambridge. 391 pp.

MELICK, D.R. & SEPPELT, R.D. (1997): Vegetation patterns in relation to climatic and endogenous changes in Wilkes Land, continental Antarctica. Journal of Ecology 85: 43-56.

SCHROETER, B.; KAPPEN, L.; SCHULZ, F. (1993): Long-term measurements of microclimatic conditions in the fruticose lichen *Usnea aurantiaco-atra* in the maritime Antarctic. In: CACHO, J.& SERRAT, D. (eds.): Actas del V simposio de estudios antárticos. CICYT, Madrid: 63-69.

SCHROETER, B.; OLECH, M.; KAPPEN, L.; HEITLAND, W. (1995): Ecophysiological investigations of *Usnea antarctica* in the maritime Antarctic. I. Annual microclimatic conditions and potential primary production. Antarctic Science 7: 251-260.

SELKIRK, P.M. & SEPPELT, R.D. (1987): Species distribution within a moss bed in Greater Antarctica. Symp. Biol. Hung. 35: 279-284.

SMITH, R.I.L. (1990): Plant community dynamics in Wilkes Land, Antarctica. Proc. NIPR Symp. Polar Biology 3: 229-244.

HYDROLOGY OF MATIAS AND POTTER CREEKS

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Introduction

The hydrology of melt water creeks which drain into the Potter cove has certainly influences on this shallow water ecosystem; therefore, the aim of this study has been to recognise the dynamics of these two main creeks of the area so as to establish their runoff regime and sediment discharge into the cove and their changes through the time. Summer surveys (1993-1994 and 1996-1997) to estimate the drainage of the creeks and also to interpret water-levels and yields were carried out.

Study Area

This includes the drainage basins of Matías and Potter creeks. They both discharge directly into the south coast of the cove (Fig. 1). The geological composition of the peninsula (Fig 1) is: volcanic rocks (andesites, basalts) wich make up isolated outcrops; sedimentary rocks (conglomerates, tuffs, clays); debris slope material and glacial sediments (Fourcade, 1960). The last group is made up of cryoclastic volcanic rocks and tilly deposits (Rios et al, 1992) and form the moraines that cover most of the internal zones of the peninsula.

The shallow zone is covered by sediments mainly of volcanic origin. Their particle sizes are sandy- psephitic, except in the outlet streams zone wich are characterised by pelitic sediments.

The climate is maritime type, with strong winds from the east and west sectors and wind gusts faster than 100 km/h. Either snow or rain falls in summer season and evaporation is scanty. Release humidity is comparatively high (90% in summer). Summer record temperatures vary between -4°C and 10°C (24.8°F and 50°F).

There exist many lagoons of different sizes which are spread on beach sectors as well as on moraines. The most remarkable one is the "23 lake" (Drago; 1983) that constitutes the greatest water area of the peninsula and makes up the Matías Creek headwater.

Drainàge network

In springtime, streams start flowing through incipient streambeds within small valleys dissecting the area.

Matías creek has its source in the "23 lake" (Fig 1). Its main stem runs from SSE to NNW through a glen of about 1 km long. It has a pattern of a single channel drainage and only one tributary channel nearby the outlet. Its upper area has a slope of approximately 8% . In this area, Matías creek runs through a narrow channel and its left margin is developed by creep from the Three Brothers hillside. The lower area (approximate slope 5%) has a concrete man-made dam 80 m far from the outlet and drains into the cove through a

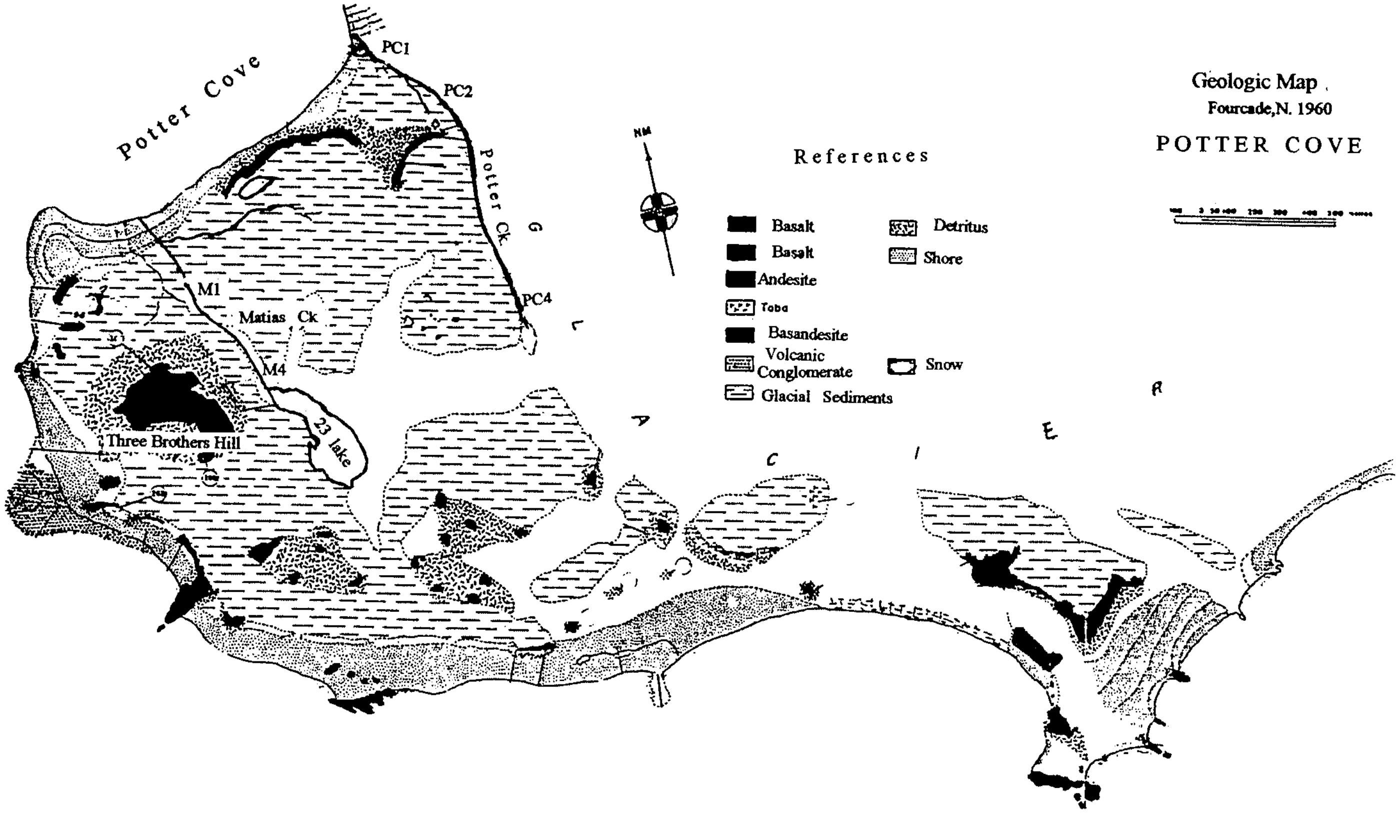
Geologic Map .
Fourcade,N. 1960
POTTER COVE
References
Basalt
Basalt
Andesite
Toba
Basandesite
Volcanic Conglomerate
Glacial Sediments
Detritus
Shore
Snow
NM
Potter Cove
PC1
PC2
PC4
Potter Ck
M1
Matias Ck
M4
Three Brothers Hill
23 lake
G L A C I E R

Fig. 1

small streambed. At the beginning of the runoff period the waterflow originates from melting snow accumulated during winter and from water of the "23 lake". When the snow disappears, waterflow is maintained both by the lake and by groundwater drainage.

Potter creek has also a pattern of single drainage. Along its right bank there is a glacier tongue.Its upper streambed has gorges larger than 2m which become smaller downstream. The lower streambed is defined by a slope change ranging from 20% at headwater to 3% in the lower zone. The latter develops a deltaic drainage pattern. This is due to a minor transport capacity of the water and/or to an excessive increase of sedimentary load. The waterflow is fed from the melting of the glacier and the snow accumulated during winter and also from groundwater drainage which flows through morainic sediments.

Hydrology

Runoff velocities were measured by float method at Matías creek (Varela, 1994) and current meter method at Potter creek (Varela, 1997). Water temperature and conductivity were also recorded and several samples were taken in order to determine the suspended-sediments load. The samples were filtered through filters that retained particles up to 2.5μ. They were subsequently dried out to constant weight.

Two stations were located at Matías creek (Fig. 1), M1 at lower streambed, near the outlet and M4 in headwaters. The approximate distance between both M1 and M4 was 800m. Record period at M1 station ranged from 09/12/93 to 09/02/94. At M4 station, recording began 24/12/93 because of the ice cover did not allow measurement.

During 1993-1994 field work, Potter creek was free of ice since 07/12/93 at lower streambed and since 26/01/94 at headwater. Control measurements were carried out from 09/12/93 to 08/02/94 in three gauge sites, two at lower zone (Pc1 and Pc2) and one (Pc4) at headwater (Fig. 1).

Systematic daily records were done from 21/12/96 to 19/02/97 at Pc1. At the beginning of the recording the basin was free of snow and ice, and according to third-party sayings the runoff had started in October. Meteorological data were obtained from the National Meteorological Service station located in the shore zone.

Discharge and suspended-sediment concentration were obtained after sampling and suspended-sediment yield from the two mentioned parameters, were estimated.

Finally, water yield, water level, suspended-sediment yield and temperature temporal tendency curves were constructed to establish their regime of runoff and sediments discharge into the cove.

Results

Runoff regime of creeks as shown in Figs. 1 and 2.

Matías Creek:

At M1 station water level and streamflow (Fig 2) increased between 09/12/93 and 27/12/93. The daily mean temperature was between -1°C and 2°C (30.2°F and 35.6°F). From 27/12/93 to 09/02/94 water levels and discharges were relatively constant in spite of the increase of daily mean temperature.

The daily discharge fluctuations ranged between $0.11 m^3/s$ and $0.03 m^3/s$ (Fig.2).

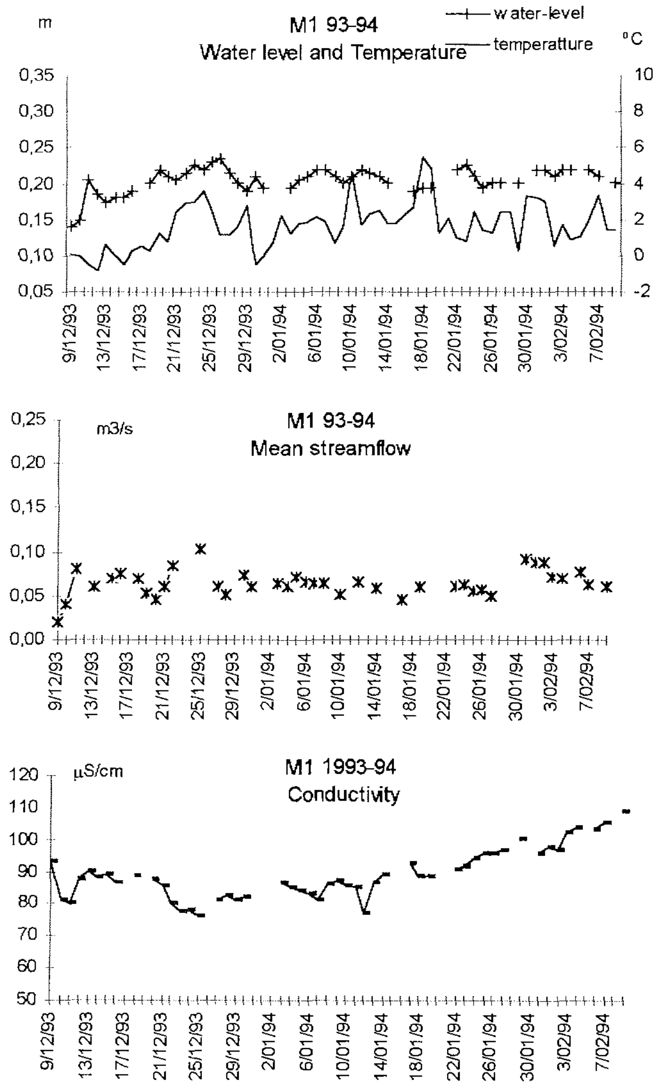

Fig. 2
Hydrological data obteined at station M1 (Matías Creek) 1993-1994.

Total drained volume was 0.34 Hm^3, for the recording period. This value was lower than the registered one for the same season in 1992-1993 (0.5 Hm^3). The water velocity had a maximum of 0.76m/s (23/12/93) and a minimum of 0.31m/s (20/12/93 to 17/01/94) with an average of 0.4m/s.

For a comparative and quantitative analysis between M1 and M4 stations, the records from 21/12/93 to 09/02/94 were taken and a mean volume drained of

0.23 Hm^3 at M4 and of 0.27 Hm^3 at M1 was obteined. The water discharge was 0.04 Hm^3 along that distance and such a period.

The values of water conductivities vary from 75 and 110 µS /cm that is, the lowest and highest values of the table; they exhibit an upward tendency from January 1994 to the end of period (Fig. 2).

Potter Creek:

During the 1993-1994 period, minimum and maximum discharges of 0.04 m^3/s and 1.2 m^3/s at Pc1 station and of 0.04 m^3/s and 1.86 m^3/s at Pc2 station were estimated respectiveley. Water velocities at both stations oscillated between 0.4 and 1.6 m/s. The hydrographs at Pc1 station (Fig. 3) showed values smaller than 0.3m^3/s from the beginning up to 03/01/93, and mean values of 0.8m^3/s from 04/01/94 to 20/01/94. This change could reflect different sources of water contribution. Water conductivities had extreme values of 20µS/cm and 85µS/cm and mean conductivities of 38µS/cm. A decreasing tendency was observed from the beginning to the end of the period.

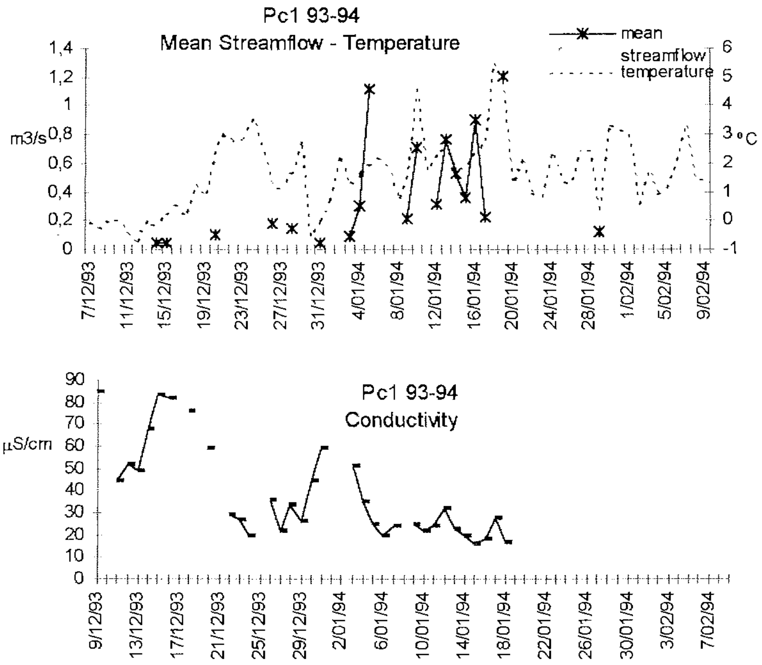

Fig. 3
Hydrological data obtained at station Pc1 (Potter Creek) 1993-1994

During 1996-1997 period, discharges were only measured at the outlet zone (Pc1) where they varied between 0.08 and 3.8m^3/s. Their temporal distribution was similar to daily mean temperature (Fig. 4). Suspended -sediment discharge showed values between 5g/s and 60000g/s, although most frequent values were smaller than 5000 g/s (Fig. 4). Suspended-sediment concentration values at the moment of sampling ranged from 0.04 to 15 g/l, although the mode was 0.14 g/l.

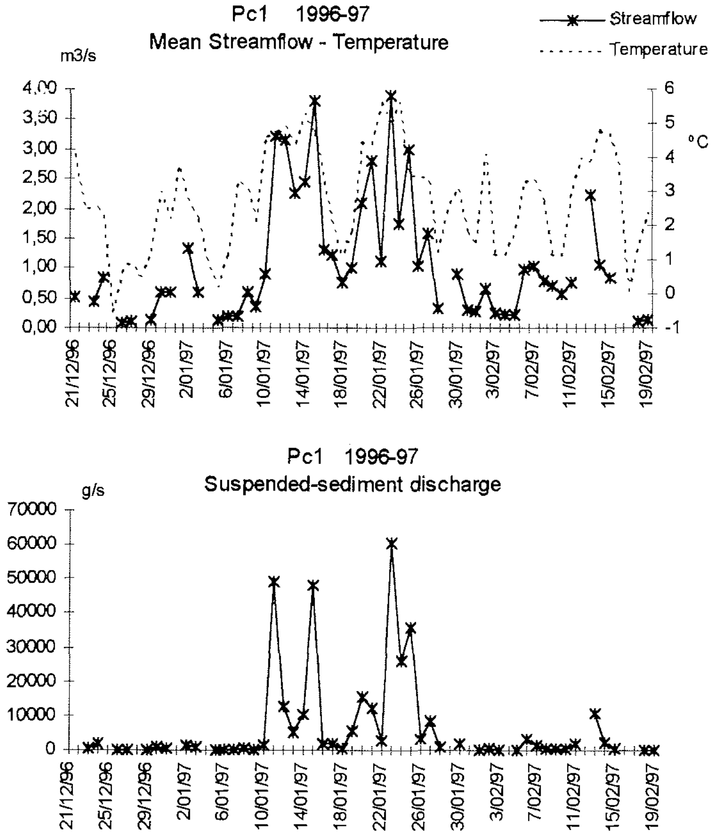

Fig. 4
Hydrological data obtained at station Pc1 (Potter creek) 1996-1997

Conclusions

Temporal variability in daily mean discharge showed the different types of contribution in both creeks. At the beginning of measuring period 1993-1994, snow-melt was the major source for water of Matías creek. After 27/12/93 the greatest waterflow contribution was from the "23 lake". Potter creek showed greater amplitude of variations and greater values of discharges than Matías creek in all recording periods.

Water conductivity exhibited very low values. At Potter creek, mean conductivities were lower (38μS/cm) than Matías creek (90μS/cm). Furthermore, Matías Creek exhibited a gradual increment of conductivity from the beginning to the end of the study period in spite of the constant yields shown.

Both streams have mixed regimes: Matías creek is snowy and lacustrine, while Potter creek is snowy and glacial.

References

Drago,E. 1983 . Estudios limnológicos en la Península Potter, Isla 25 de Mayo (Shetland del Sur): Morfología de ambientes lénticos. Instituto Antártico Argentino. Contribución Nº 265 Pp. 1:19. Buenos Aires.

Del Río, JL, Gaido,E, Walter, M y M Camino. 1992. Aspectos sedimentarios y dinámicos de las playas de caleta Potter y Península del Cerro Tres hermanos. Isla 25 de Mayo, Shetland del Sur. Antártida Argentina. Instituto Antártico Argentino. Contribución Nº 406.Pp. 1:56. Buenos Aires.

Fourcade, N. 1960. .Estudio geológico-petrográfico de caleta Potter, Isla 25 de Mayo, Islas Shetland del Sur. Instituto Antártico Argentino. Publicación N°8. Pp. 17-119. Buenos Aires

Varela, L. 1994. Régimen fluvial en el arroyo Matías (península Potter, Isla 25 de Mayo). 3as. Jornadas de Comunicaciones Científicas sobre Investigaciones Antárticas. Pp. 439:442. Buenos Aires.

Varela, L. 1997. Estimación del caudal sólido en el arroyo Potter. Caleta Potter, Isla 25 de Mayo, Shetland del Sur. IV Jornadas sobre Investigaciones Antárticas. Buenos Aires.

Wind-Driven Circulation in Potter Cove

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Introduction

Direct current measurements were carried out at Potter Cove to support the increasing scientific activity at Jubany Station.

Roese et al. (1993) presented preliminary results about the circulation pattern at Potter Cove. Klöser et al. (1994) contributed with a hydrographic description of the cove. Later, Schloss et al. (1997) made an analysis of the relative importance of wind and tide in the turbulent kinetic energy generation. Afterwards, Speroni et al. (1997) studied the sediment transport by wave generated littoral currents and finally, Roese (1998) presented a study of currents, tides and waves of the cove.

The cove presents a very complex marine circulation as a result of different current systems produced by the wind field, the mixed tidal regime, the wave climate and density gradients which in turn are affected by bottom topography, meltwater input and pack-ice formation.

The present work is focused on a detailed analysis of the wind-induced circulation of the inner sector based on direct current measurements.

Investigation area

Potter Cove is located at the south-western end of King George Island, which is part of the Shetland Archipelago. The cove (fig. 1) covers an area of about 7 km^2 and can be considered as having two sectors, the outer one, the main axis of which (1 km long) runs in a SW-NE direction with depths exceeding the 100 m, and the inner one, with depths between 30 and 50 m, the main axis of wich (2 km long) runs in a WSW-ENE direction. Within the inner sector the southern coast, where Jubany Station lies and the Three Brothers Hill (180 m high) stands as a distinctive feature, shows smoothly sloped beaches made up of sand and gravel. There are also two deltas as a consequence of the discharge of melt water streams. The northern and eastern coasts present glaciers and they are steeper than the southern coast (fig. 2). The semi-enclosed environment and the muddy nature of the bottom makes it an outstanding anchorage place. Almost every winter the waters of the cove freeze with a pack thickness of about 1 m while the rest of the year the cove is invaded by drifting ice. During the winter of 1994 the cove was frozen only at the very inner sector.

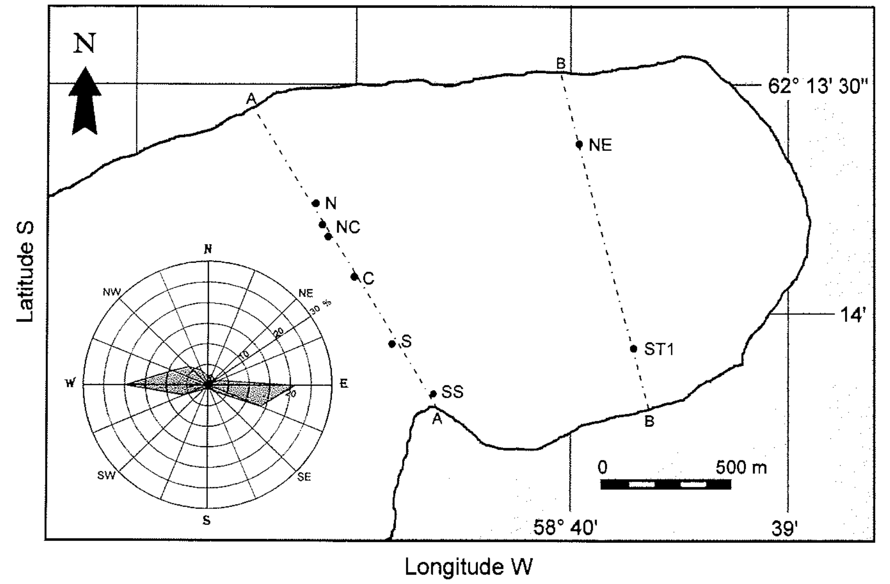

Figure 1: Potter Cove. Location of mooring sites and wind direction distribution (heavy shade, in percentage) for summer 1992. Light shades indicate the quadrants adopted for west and east winds.

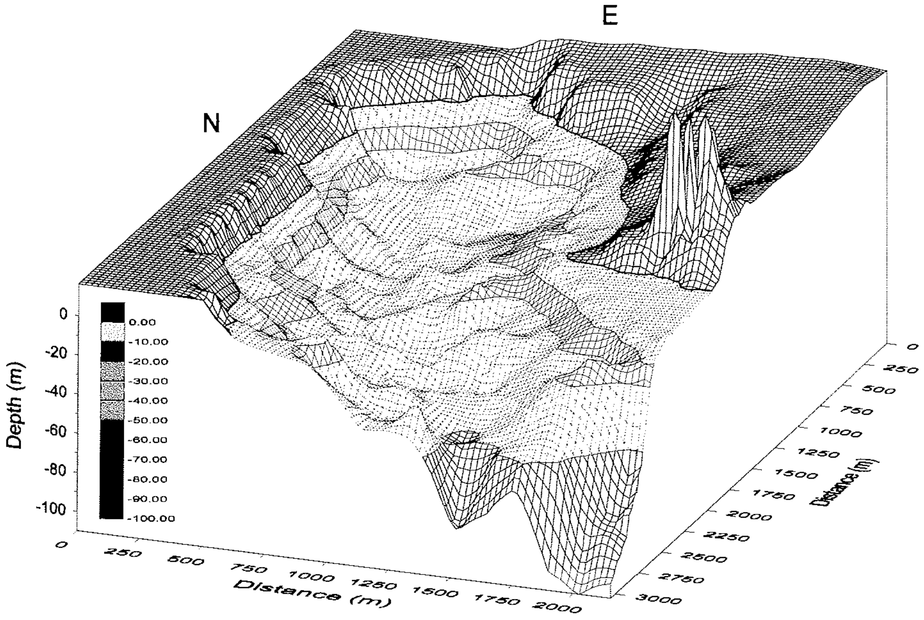

Figure 2: Bottom topography of Potter Cove. Surface computed with soundings taken from the SIHN chart H-711. Grid elements are of 25 x 25 mts. Vertical scale has been exaggerated for a better appreciation of bathimetric features. Isobaths of 0, 10, 20 and 50 metres are shown.

Data

Direct current measurements were performed at eight sites in Potter Cove (inner sector) (fig. 1) during the austral summer of 1992 and the austral winter of 1994. The instruments used were Aanderaa RCM5 set with sampling intervals of 30 minutes. The fifteen current records are summarised in table 1.

Hourly wind records were obtained for all the current sampling periods from the meteorological station at Jubany and interpolated to obtain wind time series with the same period as for the currents time series (30 minutes).

Table 1: Current stations

Station	Depth Instrument & Site (m)		Days	Observation Period
N	15	33	18	02/03/92 - 20/03/92
N	25	33	18	02/03/92 - 20/03/92
NC	5	50	50	26/08/94 - 15/10/94
NC	15	40	21	24/09/94 - 15/10/94
C	15	46	8	21/02/92 - 29/02/92
C	25	46	8	21/02/92 - 29/02/92
S	5	35	29	26/08/94 - 24/09/94
S	15	30	9	21/02/92 - 01/03/92
S	25	30	9	21/02/92 - 01/03/92
SS	5	15	7	02/03/92 - 09/03/92
SS	10	15	7	02/03/92 - 09/03/92
NE	15	26	9	21/03/92 - 30/03/92
NE	25	26	9	21/03/92 - 30/03/92
ST1	15	30	9	21/03/92 - 30/03/92
ST1	25	30	8	22/03/92 - 30/03/92

Data processing

Equipment and time limitations made that in order to obtain a good spatial coverage, sacrifices had to be made in terms of simultaneity and record lenght (see Table 1).

In order to reach a better understanding of the water dynamics in Potter Cove it is necessary to separate the current-forcing causes. An effective method to do so is to apply a low-pass filter to the current records that allows to separate the wind-induced current from the tidal current. The mixed tidal regime with a strong semidiurnal predominance, presents a maximum amplitude of 2.14 m and a mean amplitude of 1.08 m. Since the four main harmonic components of the tide in Potter Cove account for almost the 90% of the amplitude, and their periods do not exceed 28 hours, retaining periods longer than those allows for the removal of main tidal effects and to keep the drift current. The same filter was applied to the wind records to remove noise and any possible daily variability.

Taking into account and anticipating the E-W bidirectionality, two cases were considered for analysis of the drift-current; the east wind case (EWC) for the NE-SE quadrant and the west wind case (WWC) for the SW-NW quadrant.

Synchronising the wind and current records, the filtered current values of each current site that correspond to different wind intensity intervals (WIIs) for the two wind cases EWC and WWC have been extracted and averaged to obtain single vectors for making the vertical sections A-A and B-B as a way to present respective characteristics in the circulation pattern (figs. 3 and 4).

Results

The observed magnitudes for the currents are very low with mean values up to 3.5 cm/sec and maximum ones up to 20 cm/sec. Drift-current mean values are even lower and do not exceed 3 cm/s while maximum ones reach 12 cm/s.

The wind field for the two sampling periods showed a pronounced E-W bidirectionality and in about 80 % of the cases the wind values fell into the quadrants NE-SE and SW-NW being more evenly distributed (40% of NE-SE and 40% of SW-NW) during the period of summer 1992 (fig. 1). The period of winter 1994 (not shown) presented a predominance of the SW-NW quadrant.

The wind-driven circulation pattern at Potter cove is highly dependent on the wind intensity.

For WWC (fig. 3), A-A section, and for wind intensities lower than 8 m/s the water enters the cove by the north and exits by the south at all depths while the same occurs at B-B section for all WIIs except for 4-6 m/s interval where the st. NE at 15 m shows outflow. It can be noted at A-A section that when the W wind intensity increases the southern exit extends to the north and the incoming water is confined to a thinner surface layer. The last feature can specially be noted at st. N and NC where for wind intensities lower than 8 m/s the water enters the cove at all depths, for 8 to 9 m/s an opposite deep current can be observed, the wich reverts between 15 and 25 m, for 9 to 12.5 m/s this reversion is at about 15 m, for 12.5 to 17 m/s between 5 to 15 m and for more than 17 m/s shallower than 5 m. Unfortunately, because current records are short and consecuently no wind values for some WIIs have been recorded, some points remain uncertain.

For EWC (fig. 4), section A-A, the water exits the cove by a surface layer of about 10 meters and enters below it for all the WIIs, being the only difference between the two WIIs the st S, 25 m. For wind intensities lower than 5 m/s, a subsurface inflow by the north and outflow by the south can be observed, except at st. S, 15 m. Also, at section B-B but for wind intensities lower than 7 m/s, the water enters by the north and exits by the south.

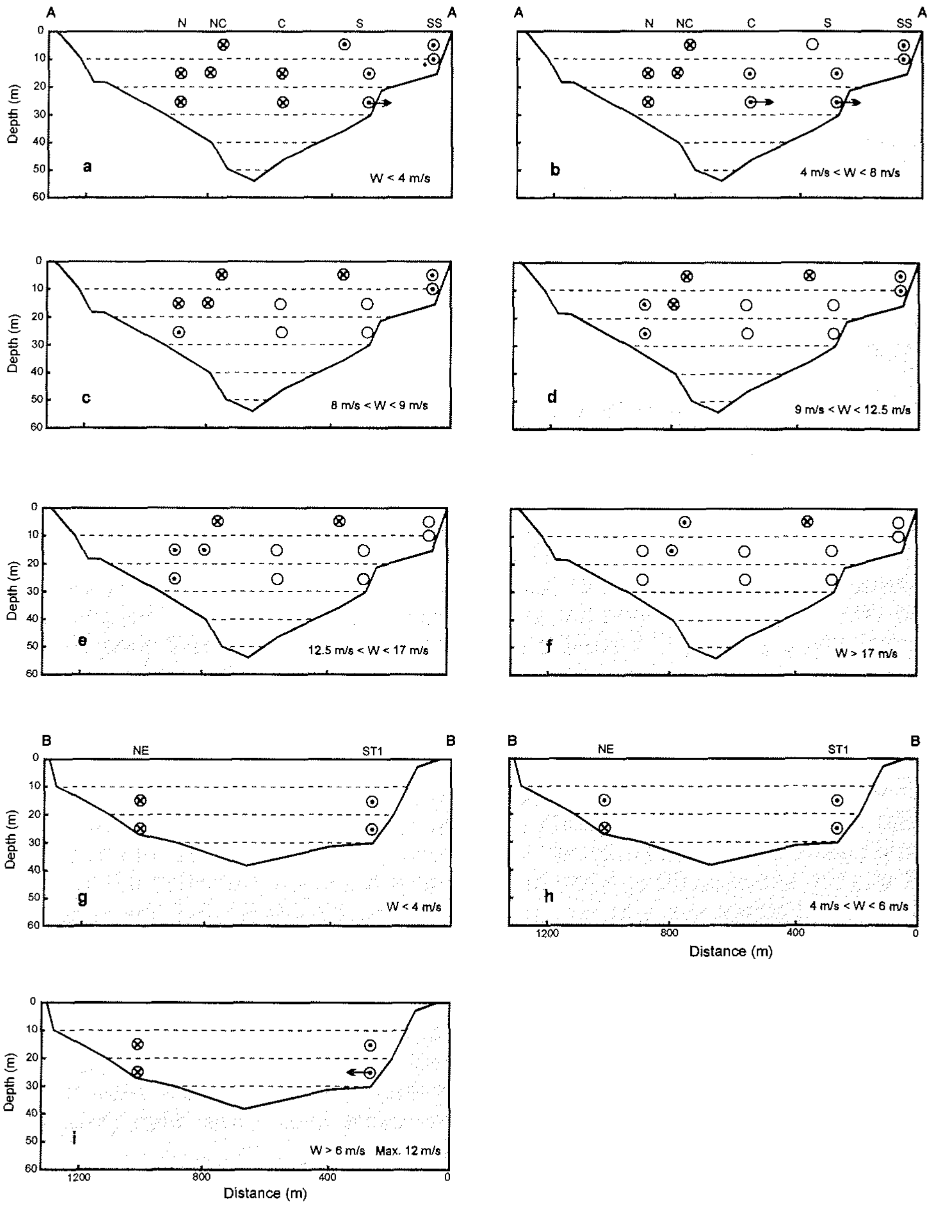

Figure 3: Vertical current sections (A - A : a, b, c, d, e, f ; B - B : g, h, i) as seen from the outside of the cove for west wind case. Crosses indicate inflow, dots outflow, blanks that no wind values were recorded for those wind intensity intervals and arrows currents the direction of wich is almost paralell to the section. Wind intensity intervals (W : west) and name of stations are also shown.

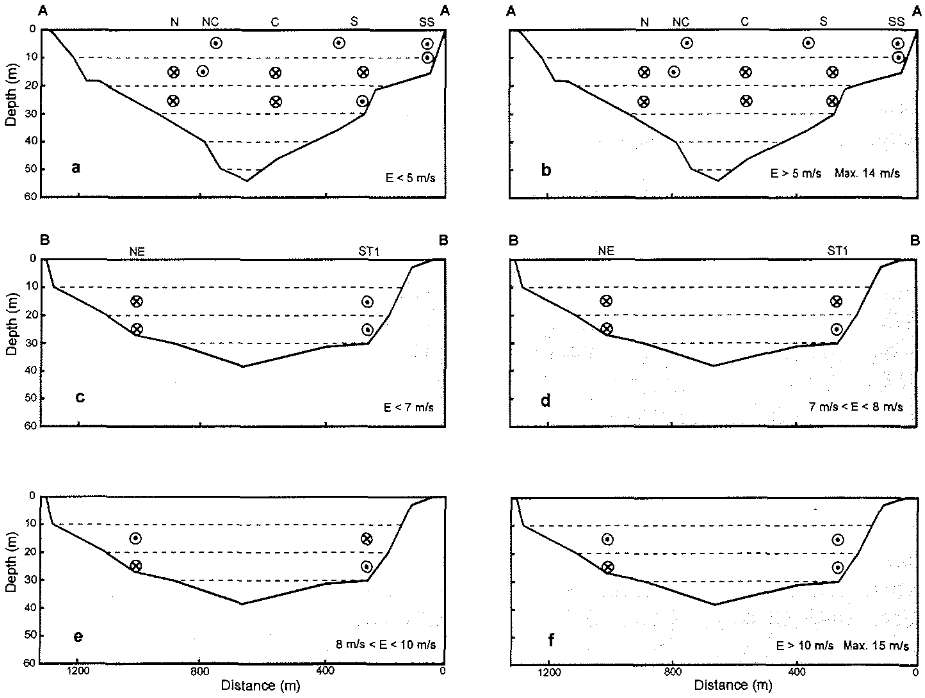

Figure 4: Vertical current sections (A - A : a, b ; B - B : c, d, e, f) as seen from the outside of the cove for east wind case. Crosses indicate inflow, dots outflow. Wind intensity intervals (E: east) and name of stations are also shown.

Conclusions

As it was pointed out earlier many of the current time series are short and not simultaneous so the results presented here must be taken as representative for the measurement period and not as a general case.

Two current systems are produced by the wind field at Potter Cove. One is a clear cyclonic gyre for W and E winds with intensities lower than 5 m/s. This cyclonic gyre indicates that the water renewal in the cove starts at the north coast while with the increase of W winds the water outflow extends more to the north.

The second current system is a vertical circulation cell with surface currents responding to the direct effect of the wind and an opposite flow in the deep layer for the WWC and EWC, leading to downwelling and upwelling, respectively at the inner sector of the cove. Also, with increasing W wind intensity, the water accumulation at the inner sector of the cove augments, the surface incoming water layer becomes thinner and consecuently the sub-surface outgoing one becomes thicker. This can be thought as an upward displacement of the no-motion layer.

Acknowledgements

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References

Klöser H., Ferreyra G., Schloss I., Mercury G., Laturnus F. and Curtosi A. (1994). Hydrography of Potter Cove, a Small Fjord-like Inlet on King George Island (South Shetlands). Estuarine, Coastal and Shelf Science, 38, pp. 523-537.

Roese M. (1998). Aspectos de la circulación en Caleta Potter, Islas Shetland del Sur, Antártida. Trabajo de Seminario, Instituto Tecnológico de Buenos Aires (unpublished).

Roese M., Speroni J., Drabble M. y Pascucci C. (1993). Mediciones de corrientes en Caleta Potter, Antártida. Jornadas Nacionales de Ciencias del Mar, UNP-CENPAT-CONICET, Puerto Madryn, abstract pp. 210 and oral presentation.

Schloss I., Ferreyra G., Gallo J. y Roese M. (1997). Importancia relativa del viento y de la marea en la generación de energía cinética turbulenta en Caleta Potter, Is. 25 de Mayo, Antártida. Cuartas Jornada sobre Comunicaciones de Investigaciones Antárticas, IAA-DNA-CONICET (in press).

Speroni J., Drabble M. y Roese M. (1997). Transporte de sedimentos por corrientes litorales en Caleta Potter, Antártida. Informe Técnico, División Oceanografía Costera, Servicio de Hidrografía Naval (in press).

Tablas de Marea, Servicio de Hidrografía Naval, H - 610, annual publication.

Dynamics of hydrogen peroxide accumulation in Potter Cove

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Hydrogen peroxide (H_2O_2) is a cytotoxic agent, which can elicit oxidative stress in marine organisms (Viarengo et al. 1998). As an uncharged molecule, H_2O_2 is of relative stability in seawater and has the capacity of permeating cell membranes (Halliwell and Gutteridge, 1986), thus entering living cells from outside. It elicits oxidative damage of membrane lipids, proteins and nucleic acids via liberation of highly reactive hydroxyl radicals and thereby can interfere with membrane transport and generally disturb cellular homeostasis (Abele-Oeschger et al. 1997). H_2O_2 production in surface waters is primarily driven by UV-induced photochemical activation of dissolved organic matter (DOM), and daily changing patterns with maximum values around noon are observed in field studies (Herrmann, 1996, Scully et al. 1996, Abele-Oeschger et al. 1997). The net accumulation of H_2O_2 is largely determined by the rate off DOM photooxidation and enzymatic H_2O_2 breakdown (catalase, peroxidase) in water and surface sediments (Cooper et al. 1990, Cooper et al. 1994, Abele-Oeschger et al. 1997).

This rather simplistic view is challenged by the fact that atmospheric wet deposition of rain and snow may carry rather high loads of H_2O_2, in fact reaching micromolar concentrations (Gunz and Hoffmann, 1990; Kamiyama et al., 1996), but the actual contribution from these sources to surface water H_2O_2 concentrations is not easily quantified.

During spring, surface waters of Potter Cove (PC) receive considerable freshwater run-off from the melting glaciers, carrying an unknown load of DOM. Since the time of ice melting coincides with the Antarctic ozone minimum, increased UV-B surface radiation might enhance photooxidation of UV-absorbing DOM. The objective of the present study was to describe the dynamics of the H_2O_2 concentrations in the water surface of PC during the ozone hole and ice melting period.

UV-B measurements and water sampling, as well as salinity measurements are described by Ferreyra et al. (this issue). A total of 15 samplings was done between November 6 to December 7 1995 at our fixed station in Potter Cove. Sampling was conducted around noon and each time samples were taken in 0, 5, 10, 20 and 30 m depth. Two additional high resolution profiles of H_2O_2 concentrations within the upper 1 m water column at 10 cm intervals were measured on November 10 and November 19, 1995, using an especially designed syringe sampler (10 x 20 ml) which allowed simultaneous collection of all water samples. H_2O_2 was measured spectrofluorimetrically using scopoletin as fluorescence indicator in a peroxidase catalyzed reaction (see Abele-Oeschger et al. 1997). DOM was measured with high temperature catalytic oxidation (HTCO) using a Shimadzu TOC 5000 Analyzer with a platinized-alumina catalyst. Samples were filtered through Whatman GF/F, sealed into 20ml glass ampoules and stored at -20°C prior to analysis.

Concentrations of 121 ± 59 µmol dissolved organic carbon per l^{-1}, equaling 1.4 mg l^{-1} , in the upper 5 m water column of PC are in the range expected for Antarctic waters. Thus glacier run-off did not cause especially high DOM concentrations in Potter Cove. Still, on days with slightly elevated DOM levels in the surface, peroxide concentrations, which normally ranged around 100 nmol l^{-1}, were also slightly higher (e.g., Nov 09: DOM 293 µmol l^{-1}, H_2O_2 300 nmol l^{-1}; Nov 21: DOM 197 µmol l^{-1}, H_2O_2 450 nmol l^{-1}). There was, however, no clear correlation between the two parameters over the time of our measurements.

Highest peroxide concentrations in the water column were found in surface samples (0 m) above the pycnocline. (The pycnocline was located between 0 and 5 m water depth throughout the whole sampling period, obviously due to constant fresh water run-off from the glaciers, data not shown). Although surface H_2O_2 concentrations ranged around 100 nmol l^{-1}, comparable to other oceanic environments, no correlation existed between hydrogen peroxide surface concentrations (0m) and daily UVB surface radiation (Fig. 1a, correlation coefficient $r = -0.40$, $P > 0.05$). Although there was considerable UV-B radiation (4 to 8 W m^{-2} day^{-1}, comparable to a May situation in

Bremerhaven), the amount of photodegradable DOM in Potter Cove was obviously to low to allow for detectable photooxidative H_2O_2 production.

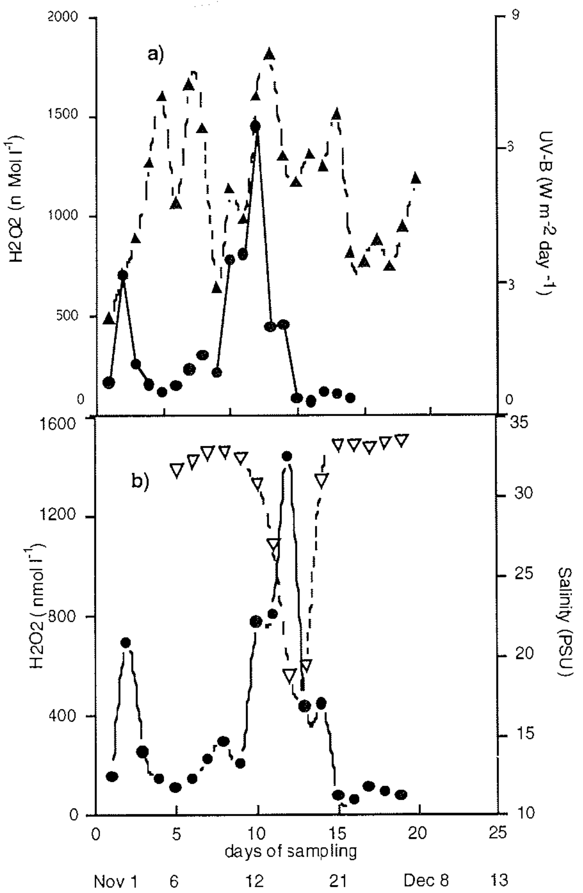

Fig. 1 : Hydrogen peroxide surface concentrations in Potter Cove (nmol l^{-1}, -●-) between November 1 and December 13 1995 in relation to a) integrated daily UV-B surface irradiation (between 295 and 320nm -▲-) and b) changes of salinity -▽- in surface waters during a snowfall event in mid November.

By contrast, H_2O_2 and salinity in surface waters displayed a significant inverse correlation (Fig. 1b; $r = -0.94$, $P < 0.01$). In mid November, shortly after the melting of the ice shield in the inner cove, a heavy snowfall caused a clear-cut drop of surface salinity from 33 to below 20 o/oo. Concurrently, H_2O_2 concentrations increased from around 200 to a maximum of 1450 nmol l^{-1} (Fig.

1b). H_2O_2 concentrations measured in samples of freshly fallen snow amounted to 13000 nmol l^{-1}.

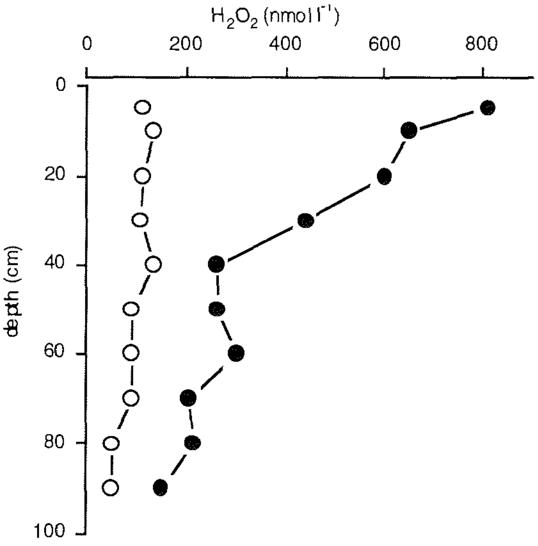

Fig. 2: Vertical distribution of the H_2O_2 concentration in the upper 1m surface water of Potter Cove before (-O-Nov 10) and during (-●- Nov 19) the snowfall event.

High resolution measurements of H_2O_2 in the upper 1m surface layer of PC before and during the snowfall event supported our finding that atmospheric wet deposition was responsible for the observed H_2O_2 maximum around November 19 (Fig. 2). Whereas the measurement from November 10 depicts a homogenous vertical distribution of peroxide with values around 100 nmol l^{-1}, on November 19 H_2O_2 concentrations in the upper 30 cm layer were significantly higher, maximal concentrations in the surface reaching as high as 800 nmol l^{-1}. Moreover, the latter profile documents downward mixing of H_2O_2 from the surface into the water column.

The analysis of our data from the Jubany UV-project during the 1995 campaign indicates that atmospheric wet deposition was the main source of H_2O_2 accumulation in surface waters of Potter Cove. Photooxidative activation of UV-absorbing dissolved organic matter, which triggers H_2O_2 dynamics in most temperate oceanic and coastal waters (Price et al. 1992, Abele-Oeschger et al 1997), did not account for significant in-situ H_2O_2 production at King George Island. The significance of the accumulation of this cytotoxic active oxygen species for the chemistry and the biology of the Potter Cove ecosystem still has to be evaluated.

References

Abele-Oeschger, D., Sartoris, F.J. and Pörtner, H.O. (1997). Effect of elevated hydrogen peroxide levels on aerobic metabolic rate, lactate formation, ATP homeostasis and intracellular pH in the sand shrimp Crangon crangon. Comp. Biochem. Physiol. 117C, 2: 123-129.

Abele-Oeschger, D., H. Tüg, R. Röttgers (1997). Dynamics of UV-driven hydrogen peroxide formation on an intertidal sandflat. Limnol. & Oceanogr. 42(6): 1406 -1415.

Cooper, W.J., Shao, C., Lean, D.R.S., Gordon, A.S. and Scully, F.E. (1994). Factors affecting the distribution of H2O2 in surface waters. In: Environmental chemistry of lakes and reservoirs. Chem. Ser. 237, ACS:393-422.

Cooper, W.J. and Zepp, R.G. (1990). Hydrogen peroxide decay in waters with suspended soils: Evidence for biologically mediated processes. Can. J. Fish. Aquat. Sci. 47:888-893.

Gunz, W.J. and Hoffmann, M.R. (1990). Atmospheric chemistry of peroxides: A review. Atmos. Environ. 24A:1601-1633.

Halliwell, B. and Gutteridge, J.M.C. (1986). Oxygen free redicals and iron in relation to biology and medicine: some problems and concepts.Arch. Biochem. Biophys. 246:501-514.

Herrmann, R. (1996). The daily changing pattern of hydrogen peroxide in New Zealand surface waters. Environ. Toxicol. and Chem. 15(5):652-662.

Kamiyama, K., Motoyama, H. Fujii, Y. and Watanabe, O. (1996). Distribution of hydrogen peroxide in surface snow over Antarctic ice sheet. Atmos. Environ. 30(6):967-972.

Price D., P. J. Worsfold, R.F.C. Mantoura (1992). Hydrogen peroxide in the marine environment: cycling and methods of analysis. Trends Anal. Chem. 11, 10, 379-384.

Scully, N. M., D. J. McQueen, D. R. S. Lean, W. J. Cooper (1996). Hydrogen peroxide formation: The interaction of ultraviolet radiation and dissolved organic carbon in lake waters along a 43-75°N gradient. Limnol. Oceanogr., 41(3), 540-548.

Viarengo, A., D. Abele-Oeschger, B. Burlando (1998). Effects of low temperature on prooxidants and antioxidant defence systems in marine organisms. In: H. O. Pörtner & R. Playle (eds.), Cold Ocean Physiology, Cambridge University Press: 213 -235.

2. STRUCTURE AND DYNAMICS OF THE ECOSYSTEM

Components of terrestrial vegetation, pattern and processes

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Introduction

The Potter Peninsula comprises an area of several square kilometres free of permanent snow and ice cover which is comparatively large at the South Shetland Islands. The open landscape is mainly formed by moraines and consists towards the coast of beach terraces and cliffs where the most important habitats for cryptogams are found. Relatively stable substrate is found around the Three Brothers Hills (Tres Hermanos). The vegetation is unevenly distributed over the area. Moraines near the glacier are only sparsely covered by plants, whilst the vegetation cover as well as species richness is increasing at more distant moraines. A plateau located south-west of the Three Brother Hills (Tres Hermanos) is covered by an exceptional rich vegetation. It consists of two layers of plants, which each can reach 100% coverage. Several moss- and lichen species found on the Potter Peninsula are restricted to that area. The two native Antarctic vascular plants *Colobanthus quitensis* and *Deschampsia antarctica* are occurring at the Potter Peninsula mostly near the coast or in places with high nutrient supply.

The aim of this study was to analyse the floristic composition and structure of the vegetation in relation to it's habitat conditions. At a slight slope along a complex snow-cover/moisture gradient around 60 vegetation analysis were performed.

Methods

Within a transect of 12 m the vegetation structure was analysed using a grid of 10x10 with each square of 2x2 cm. The transect leaded from an area with continuous moss layer to gentle, well drained slope to a two layered association of lichens and mosses. First the dominant species were registered, then each square was subdivided into 4 subquadrates in which the occurrence of all species recognisable in the field were recorded, leading to a resolution of frequencies of occurrence of 0.25% and 1% for dominance in a complete grid. Death and coverage of each species were recorded separately. When young peat was present, plant remains were identified with a hand-lens.

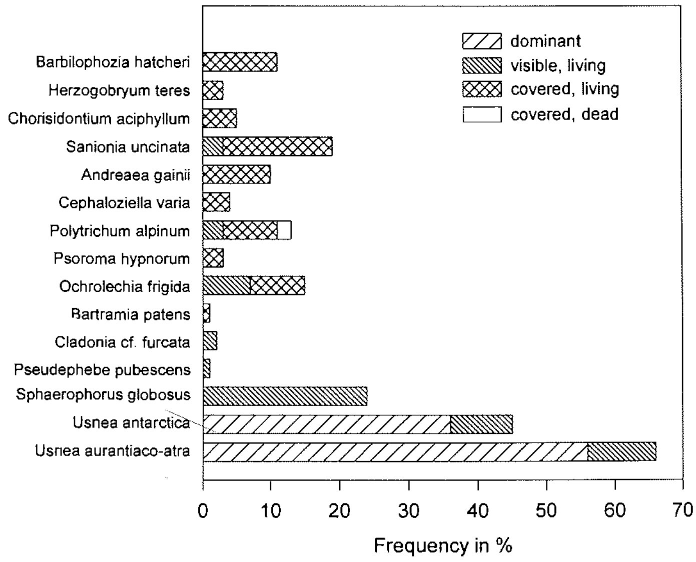
In two layered plots relative light input was measured by means of a small photodiode (Hamamatsu, Japan) inserted under the lichen layer.

Results

In the lower parts of the transect pleurocarpous mosses such as *Sanionia uncinata* and *Calliergon sarmentosum* are dominating, whereas rocks are mostly covered by the crustose lichen *Lecidea sciatrapha.* Higher up on the slope where the ground is better drained and the snow cover shorter cushion forming mosses like *Andreaea regularis* and *Andreaea gainii* are dominating, often together with *Himantormia lugubris*. Bryophilous lichens such as *Psoroma hypnorum* and a number of acrocarpous mosses are frequent associates. At the upper end of the transect where snow cover rarely exceeds 10 cm even in winter a two layered canopy build of lichens and mosses is formed.

The upper layer consists of fruticose lichens such as *Usnea aurantiaco-atra*, *U. antarctica* and *Pseudephebe pubescens*. The understorey consists of an assemblage of various species of mosses and hepatics. *U. aurantiaco-atra* and *Himantormia lugubris* are often interwoven mats of prostrate form without apothecia. The upper layer is discontinuous. In the apertures the dicranoid moss *Chorisodontium aciphyllum* and cushion forming fruticose lichens such as *Sphaerophorus globosus* are present. The most abundant bryophilous lichen is *Ochrolechia frigida*. Species richness is increasing from the locations with the longest snow-cover to the highest parts of the transect. Figure 1 presents a typical plot of 400 cm² from the upper part of the transect totally covered by

Figure 1



fruticose lichens. It demonstrates the existence of several moss and lichen species in the understorey, even if the average incoming irradiation is reduced to 13.4 % of the ambient (min 1% max. 50%, Std. err. 1.9).

In comparison with unsheltered moss stands in the lichen covered lower layer the species composition of the moss species is strongly changed. *Barbilophozia hatcheri* occurs mainly under dense mats of *Usnea aurantiaco-atra* or mixed in cushions of the moos *Chorisodontium aciphyllum*, but rarely can be found in pure stands. In contrast, *C. aciphyllum* which partly dominates the open vegetation, is getting scanty under lichen cover and sometimes areas with dead thalli are present. Also dead thalli of *Polytrichum alpinum* indicate that for some species the situation unfavourable, but only minor differences in light levels between living and dead stands of *P. alpinum* occurring in the lower layer are observable. Therefore other factors like water availability are assumed to play a decisive role.

Plant remains in shallow peat formed by *Calliergon sarmentosum*, *Sanionia uncinata* or *Chorisodontium aciphyllum* often include species which are not present in the living layer above.

Discussion

The observed vegetation pattern corresponds only roughly to those made by LINDSAY (1971) in his account of the vegetation of the South Shetland Islands. Despite the fact that Lindsay visited 35 places on 8 islands, including the Potter Peninsula (as Three Brothers Hill and environs) he never mentioned the bi-layered associations with it's remarkable floristic richness. For the South Shetland Islands the moss *Amblystegium subvarium* is only known near the Three Brothers Hill (KANDA 1987). *Psilopilum trichodon* was only found in two other localities in the Antarctic (GREENE et al. 1970). Appendix A gives a complete list of mosses found in the vicinity of the Three Brothers Hill. The main reason for the formation of this rich vegetation may be a stable substratum which is well drained and ice-free for a long period. Microclimatic conditions may also play an important role.

One major question is how dynamic these communities are and how they develop. Because of the slow growth of lichens and mosses in the Antarctic data about the productivity are scarce. HOOKER (1980) measured the production of the lichens *Usnea aurantiaco-atra* and *U. antarctica* over a two years period. He demonstrated age dependent growth rates for both lichen species leading to an estimated age of 200 years of a thallus of 1g growing on rocks. Other authors (WILLKOMM et al. 1991) found an age of 30 years by C^{14}-dating. KAPPEN and REDON (1987) demonstrated that prostrate forms of *U. aurantiaco-atra* have a photosynthetic capacity of a third of those of the erect form. With respect to microclimatic data it can be assumed that in stands with prostrate forms growth is equally reduced, but standing biomass is still high (i.e. 1 kg * m^{-2} *U. aurantiaco-atra*). Growth and productivity of bryophytes has been investigated by COLLINS et al. (1973), demonstrating for *Sanionia uncinata* an increment up to 30% each year. Decomposition rates are similar and consequently no accumulation of biomass occurs. At the Potter Peninsula peat accumulation is very weak, rarely exceeding 10 cm. Comparing the different growth rates of lichens and mosses, lichens should be easily outcompeted by mosses, but this cannot be confirmed at this stage. HOOKER (1980) supposed that *Usnea* species are "floating" on the moss which coincides with our observations on the Potter Peninsula. "Floating" means that the underlying mosses pushes the lichens upwards while they grow up. Therefore they are not capable to overtop them even if they grow faster. Moreover dense mats of fruticose lichens are well capable to suppress moss growth in the lower layer by a strong - up to 99.5% - light reduction.

The picture of the development and current state of the investigated rich vegetation types is not clear. The fruticose lichen *Himantormia lugubris*, even when partly dominant, seems to be slightly regressive and incapable to reestablish in terrestrial vegetation. In *Usnea* species reestablishment seems to be possible by thallus fragments, but it remains questionable whether they are capable to expand their stands. This raises the question whether the richest vegetation types of the maritime Antarctic are dominated by lichens which are more or less relicts of the former vegetation, implying that slight "catastrophes" such as nesting skuas or walking humans may have irreversible effects.

Literature

COLLINS, N. J.; L. C. BLISS and F. E. WIELGOLASKI (1973): Productivity of selected bryophyte communities in the maritime Antarctic.: 177-183.

GREENE, S.W.; D. M. GREENE; P. D. BROWN and J. M. PACEY (1970): Antarctic moss flora. I. The genera *Andreaea*, *Pohlia*, *Polytrichum*, *Psilopilum* and *Sarconeurum*. Sci. Rep. Brit. Antarct. Surv. 64 : 1-118.

HOOKER, T.N. (1980): Growth and production of *Usnea antarctica* and *U. fasciata* on Signy Island, South Orkney Islands. Brit. Antarct. Surv. Bull. 50: 35-49.

KAPPEN, L. and J. REDON (1987): Photosynthesis and water relations of three maritime Antarctic lichen species. Flora. 179 : 215-229.

KANDA, H. (1987): Catalogue of moss specimen from Antarctica and adjacent Regions. National Inst. Polar Research. Tokyo Press. 186 p.

LINDSAY, D.C. (1971): Vegetation of the South Shetland Islands. Brit. Antarct. Surv. Bull. 25 : 59-83.

WILLKOMM, H., M. BÖLTER and L. KAPPEN (1991): Age estimation of Antarctic macrolichens by radiocarbon measurements. Polarforschung. 61 : 103-112.

Appendix A: List of moss species found in the vicinity of Three Brothers Hill (Tres Hermanos)

Hepatics

1. *Anthelia juratzkana* (Limpr. In Cohn) Trev.
2. *Barbilophozia hatcheri* (Steph.) Hässel
3. *Cephaloziella varians* (Gott. in Neum.) Steph.
4. *Herzogobryum teres* (Carringt. & Pears.) Grolle
5. *Lophozia excisa* (Dicks.) Dum.
6. *Pachyglossa dissitifolia* Herz. & Grolle

Musci

1. *Amblystegium subvarium* Broth.
2. *Andreaea depressinervis* Card.
3. *Andreaea gainii* Card.
4. *Andreaea regularis* C. Müll.
5. *Bartramia patens* Brid.
6. *Brachythecium austro-salebrosum* (C. Müll.) Kindb.
7. *Bryum pseudotriquetrum* (Hedw.) Gärtn. Meyer et Scherb.
8. *Bryum* sp.
9. *Calliergon sarmentosum* (Wahlenb.) Kindb.
10. *Ceratodon purpureus* (Hedw.) Brid.
11. *Conostomum magellanicum* Sull.
12. *Ditrichum austro-georgicum* (Card.) Seppelt
13. *Dicranoweisia antarctica* (C. Müll.) Kindb.
14. *Dicranoweisia grimmiacea* (C. Müll.) Broth.
15. *Encalypta rhaptocarpa* Schwaegr.
16. *Pohlia cruda* (Hedw.) Lindb.
17. *Pohlia inflexa* (C. Müll.) Wijk et Marg.
18. *Polytrichum alpestre* Hoppe
19. *Polytrichum alpinum* Hedw.
20. *Pottia austro-georgica* Card.
21. *Psilopilum trichodon* (Hook. F. & Wils.) Mitt.
22. *Racomitrium austro-georgicum* Par.
23. *Sanionia uncinata* (Hedw.) Loeske
24. *Schistidium antarctici* (Card.) Savicz. et Smirn.
25. *Tortula filaris* (C. Müll.) Broth.
26. *Tortula princeps* De Not.
27. *Tortula saxicola* Card.

Seasonal Variation of the Conditions for Phytoplankton Growth in Potter Cove

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Phytoplankton studies have been carried out in Potter Cove (Fig. 1) since November 1991, in the frame of the CS-EASIZ Programme. Several hydrographic and meteorological parameters have been measured while phytoplankton was continuously sampled. Some experimental work was done in order to understand the relationship between dynamic processes in the water column and biological variables. Spring-summer and winter seasons were both considered. Although part of the results were already published (see Klöser et al. 1993 and 1994, Anonymous, 1994, Schloss, 1997, Schloss et al., 1997, where all the methods were described) here we will do an attempt to summarise some aspects of the above mentioned information, and try to explain the trends observed and factors governing phytoplankton variation.

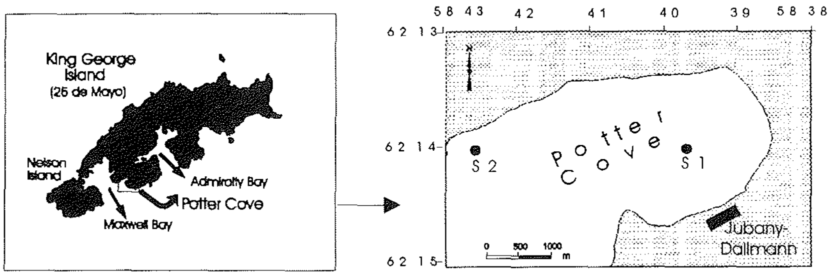

Figure 1: Map showing the location of Potter Cove and one of the sampling sites studied, S1, in the inner cove.

Environmental information

The information here presented corresponds mostly to the 1995 - 1996 summer campaign, when a daily sampling on station S1 (in the inner part of Potter Cove) was done, and to the year between October 1995 and October 1996. Vertical stratification in hydrographic parameters (temperature, salinity, density) could only be observed during the spring-summer seasons, as it can be seen in Figure 2. Density gradients were enhanced due to fresh water inputs from melting sea ice and glaciers at the beginning of the growth season and by riverine discharge later on. Even during this period, stratification might have been disrupted by episodic high intensity wind events, as indicated in Figure 2. Furthemore, the pycnocline could sometimes be found at very shallow depths, o even be absent, so that the water column would be better defined as a continuously stratified system, like it was described by Holm-Hansen et al. (1989).

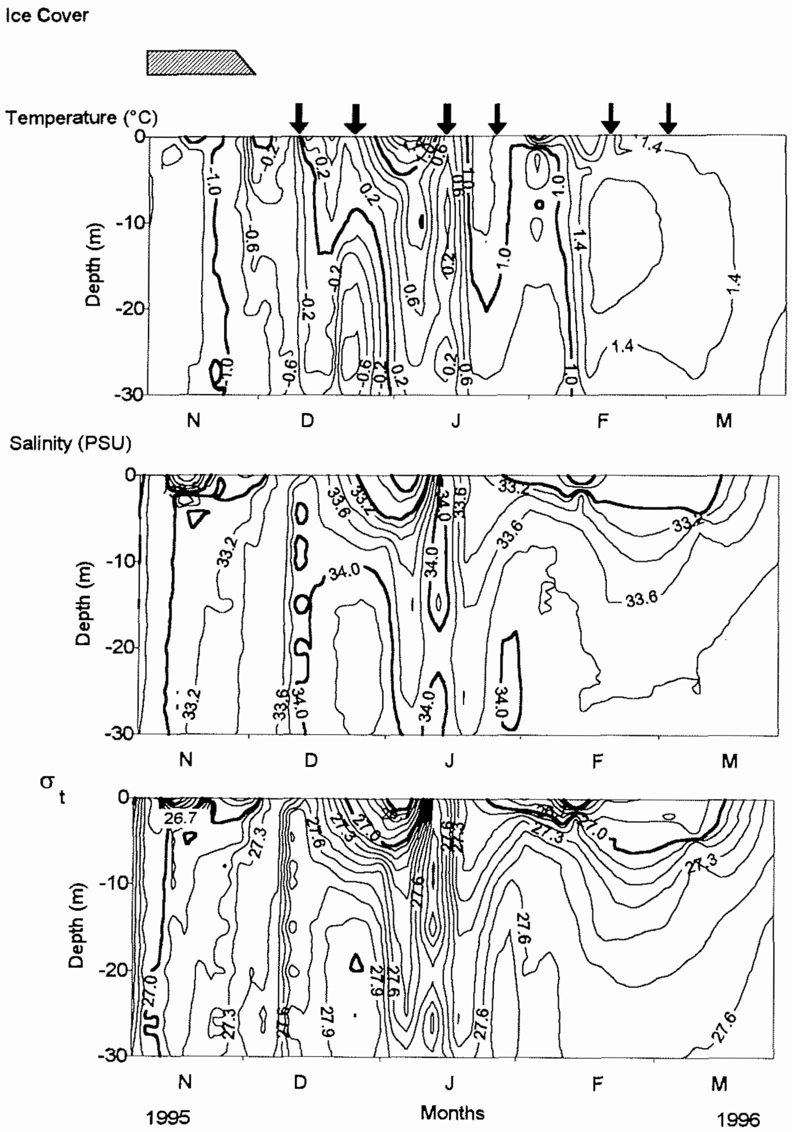

Figure 2: Variation of some hydrographic parameters during a summer season (1995-1996), when the inner cove was intensively sampled. In the upper part of the figure ice cover is shown. Arrows indicate the dates when daily average wind speeds were > 12 m s^{-1}.

To summarise the seasonal variation in these hydrographic parameters, considering the data from the year-round survey between October 1995 and October 1996 (Fig. 3) we could say that low-temperature and low-salinity waters characterised the spring season, warmer and more saline waters were typical during summer, while in winter waters showed low temperature and high salinity.

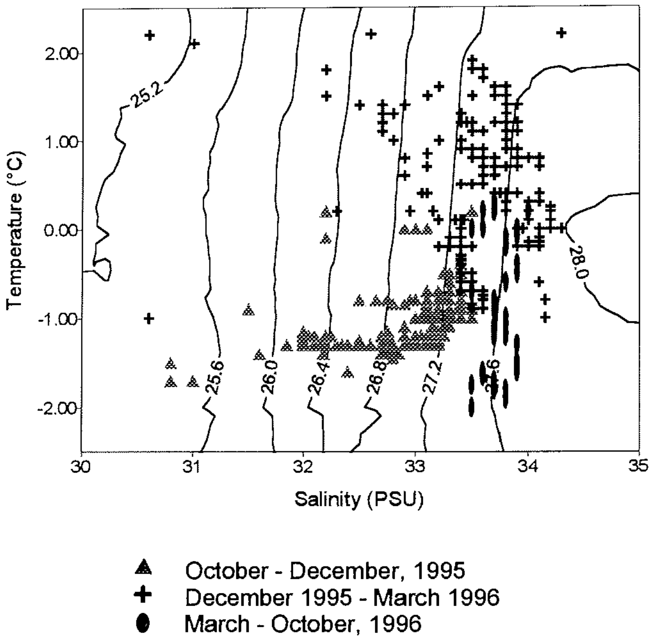

Figure 3: TS diagram showing the temporal variability of some hydrographic parameters in Potter Cove.

As for other Antarctic environments (Bidigare et al., 1996), nitrate, phosphate and silicate concentrations during the spring-summer season during all the studied periods were always such that no phytoplankton growth limitation was expected. The ranges were 15 to 30 µM, 1.6 to 3 µM and 34 to 55 µM for nitrate, phosphate, and silicate, respectively.

Dominant wind directions were W and E, in coincidence with the main axis of the inner cove (Fig. 1), and strongly influenced surface water circulation. Wind speed averages presented values around 8-11 m s^{-1} (Tab. 1). These high wind speeds were a common feature during all the seasons studied and had a highly negative impact on water column stability. The kinetic energy produced by the average winds blowing during 3-5 hours was higher than the potential energy of the water column (Schloss, 1997). This fact was of key importance for phytoplankton growth, as it will be shown below.

Table 1: Wind speed and direction in Potter Cove during different periods studied.

Period	Maximum speed ($m\ s^{-1}$)	Average speed ($m\ s^{-1}$)	Mode	Dominant directions (%)	
				E	W
October'91 - March'92	28.8	7.9	12	38	27
Year 1992	28.8	8.5	10	27	34
September'93 - March'94	25.5	9.9	10	16	38
October'95 - March'96	30	9	10	16	60
Year 1996	41.5	11	11	21	46

Both winds and tides can generate turbulent kinetic energy (TKE) (Demers et al., 1987), which results in vertical mixing of the water column (Mann and Lazier, 1991). In coastal environments such as Potter Cove wind- more than tide-generated TKE (Schloss, 1997) can destabilise the water column stratification. The vertical transport of particles will be a function of wind speed and duration, and of the water column density gradient (Denman and Gargett, 1983). We calculated the depths of vertical lagrangian transport of particles, $Z_{(t)}$, following Denman and Gargett (1983). Our computations suggest that in coastal shallow environments $Z_{(t)}$ can explain the vertical distribution of particles in the water column better than just the depth of the mixed layer (Schloss, 1997). Monthly averages of $Z_{(t)}$ are presented in Table 2. They have been calculated considering all the campaigns studied.

Table 2: Daily integrated PAR values, K (PAR extinction coefficient) for the water surface layer, $Z_{(c)}$ and $Z_{(t)}$ for Antarctic phytoplankton growth season. Data correspond to monthly averages.

	Average PAR ($E\ m^{-2}\ d^{-1}$)	K (m^{-1})	$Z_{(c)}$ (m)	$Z_{(t)}$ (m)
October	37.96	0.43	23.35	71.0
November	41.35	0.44	24.85	29.2
December	37.93	0.63	15.92	33.7
January	30.27	0.67	11.95	19.9
February	25.49	0.73	9.23	18.4

Light (photosynthetically active radiation, PAR) intensity has been measured during several summer campaigns (Tab. 2). In the water column light penetration (Fig. 4) was also measured and K, the light attenuation coefficient, calculated following Kirk (1983). Both the euphotic and Sverdrup's (1953) critical depth, $Z_{(c)}$, were determined, the last one after the equation described by Nelson and Smith (1991).

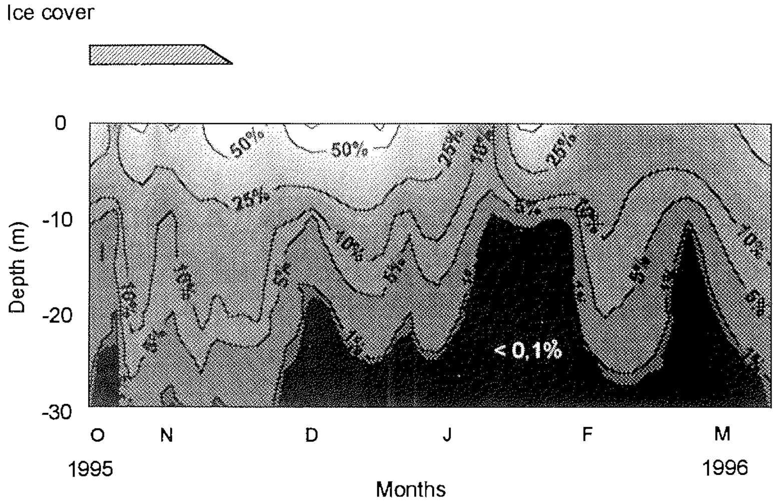

Figure 2: Temporal variation of the percentage of light penetration in the water column during the summer season 1995-1996.

In the present work we considered that it had to be $Z_{(c)}>Z_{(t)}$ to allow phytoplankton to grow and to attain chlorophyll-a concentrations > 2 $\mu g\ L^{-1}$. Moreover, we expected to find these chlorophyll-*a* concentrations whenever this favourable situations lasted for at least 10-14 days (Schloss, 1997). This interval corresponds to the lag in the beginning of Potter Cove's phytoplankton exponential growth, and was the result of several experiments performed (Schloss et al., in press). Monthly averages of both $Z_{(c)}$ and $Z_{(t)}$ are presented in Table 2. As it can be seen, on average, the dominating physical features (the realtion between the light field and water column stability) in the study area were not adequate for important phytoplankton accumulation.

Phytoplankton biomass and suspended particulate matter

Pigment concentration was determined during all summer and winter campaigns. Typically, very low chlorophyll-*a* concentrations characterised Potter Cove's waters, with maximum concentrations of 4 mg L^{-1} (Fig. 3), but around 1 mg L^{-1} on average during the growth season. Phytoplankton specific omposition during these maxima was characterised by diatoms such as *Corethron criophilum*, *Thalassiosira spp.*, *Eucampia antartica*, *Odontella weissflogii*, ice related pennate genera such as *Nitzschia spp.* and *Navicula spp.* Resuspended benthic diatoms, like *Gyrosigma spp.* or epiphytic genera (like *Licmophora spp.*) were sometimes also very abundant. Dino- and microflagellates were also present, occasionally attaining high concentrations but, in general, in lower abundance. Some of these samples were, specially during the summer, very rich in particles, related to land fresh water run off. The distribution of the suspended particulate matter (SPM) in the water column (Fig. 4) was also related to bottom resuspention events.

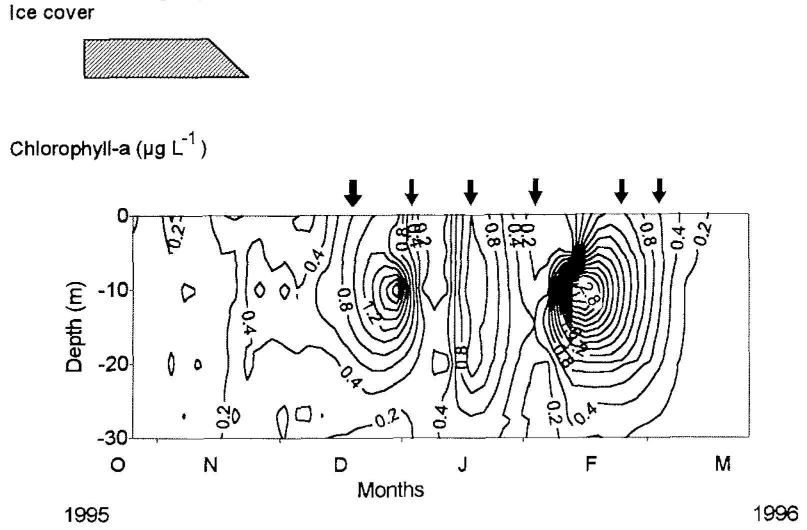

Figure 3: Temporal variation of chlorophyll-*a* concentration during the summer season 1995-1996. Arrows show the dates when wind speed was > 12 m s^{-1}. Ice cover is shown in the upper part of the figure.

Integrated chlorophyll and primary production data are presented elsewhere (see Schloss et al., this issue). Although these values are lower then those found in other coastal areas such as those located West of the Antarctic Peninsula (see Bidigare et al., 1996 and references in there), as mentioned above, in experimental studies it has been shown that Potter Cove phytoplankton may potentially grow and reach very high chlorophyll-*a* concentrations (Schloss et al., in press). Additional experiments showed that the dissolved materials present in these waters did not inhibit phytoplankton production (Schloss, 1997). No information is yet available on zooplankton or microzooplankton grazing, but these organisms did not show high densities in the study area (Elwers, pers. comm.). Therefore it was concluded that the physical environment was the main factor responsible for the low phytoplankton biomass observed during all these years. Vertical distribution of pigments also showed a strong relation with wind intensity (Fig. 3).

How did the physical environment in Potter Cove influence phytoplankton biomass?

Light limitation for photosynthesis is a known seasonal feature that polar primary producers have to cope with. Potter Cove's phytoplankton development in occasions is influenced by light limitation due to the seasonal ice cover at the beginning of the growth season (see Fig. 2). Later, when ice has melted or has been carried away, heavy fresh-water inflow, containing large amounts of organic and inorganic particles, strongly darkens the waters, so that sometimes the lower limit of the euphotic zone (with values below the 1 or 0.1 % of surface irradiance) can be found at very shallow depths (Fig. 2). This results in the high K values computed (see Tab. 2). Therefore, in this coastal shallow environment light limitation does not finish with the end of the winter. However, some temporal windows with favourable light conditions may remain open. One could occur between the end of sea ice melting and the starting of particle input coming with riverine flow. Light conditions could also be favourable at the end of summer, when much less fresh water enters the sea. It is during these periods when phytoplankton could grow and accumulate, whenever these windows last for at least 10-14 days, as mentioned above. Then, other factors like cells vertical displacement have to be considered.

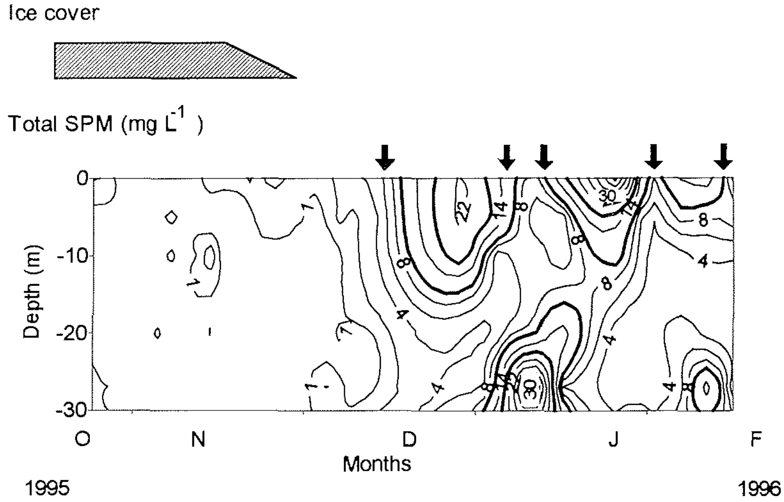

Figure 4: Temporal variation of the concentration of SPM during the summer campaign 1995-1996. The correspondence between the more intense winds (indicated with arrows) and the SPM concentrations can be noted.

$Z_{(t)}$ was on average deeper than $Z_{(c)}$. This means that the wind intensities measured in the area of Potter Cove were sufficiently strong to transport particles to depths below $Z_{(c)}$. There, according to the definition used by Nelson and Smith (1991), light was not enough to allow phytoplankton to accumulate and balance losses, so that a net increase in cell or pigment concentration could be detected. During the several seasons studied some of the mentioned windows were, in fact, observed, and winds during them weaker than the average for periods of about 7-10 days. At those times some growth was indeed observed, reaching chlorophyll-*a* concentrations of about 3-4 mg L^{-1} , as in November 1991 (Schloss et al., 1997).

Therefore we hypothesise that if this combination of factors, i.e. adequate light conditions and moderate wind intensities would last for longer periods, phytoplankton blooms like those found in other coastal zones could develop in Potter Cove. Finally, the phytoplankton biomass observed during all these years could hardly explain the benthic consumer abundance found in the inner Potter Cove. Microphytobenthic algae and organic benthic debris are suspected to account for the nutrition of the local fauna. This aspect of the Potter Cove system is currently being studied.

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References

Bidigare, R.R., Iriarte, J.L., Kang, S.H., Karentz, D., Ondrusek, M.E., and Fryxell, G.A. (1996). Phytoplankton: Quantitative and qualitative assessments. En: Ross, R.M., Hofmann, E.E. y Quetin, L.B. (eds.). Foundations for ecological research west of the Antarctic Peninsula. Antarct. Res. Ser. Vol. 70: 173-198.

Demers, S., Therriault, J.-C., Bourget, E. y Bah, A. (1987). Resuspension in the shallow sublittoral zone or a macrotidal estuarine environment:: Wind influence. Limnol. Oceanogr. 32(2): 327-339.

Denman, K.L. and Gargett, A.E. (1983). Time and space scales of vertical mixing and advection of phytoplankton in the upper ocean. Limnol. Oceanogr. 28(5): 801-815.

Holm-Hansen, O., Mitchell, B.G., Hewes, C.D. and Karl, D.M. (1989). Phytoplankton blooms in the vicinity of Palmer Station, Antarctica. Polar Biol. 10(1):49-57.

Klöser, H., Ferreyra, G., Schloss, I., Mercuri, G., Laturnus, F. and Curtosi, A. (1993). Seasonal variation of algal growth conditions in sheltered Antarctic bays: the example of Potter Cove (King George Island, South Shetlands). J. Mar. Syst. 4: 289-301.

Klöser, H., Ferreyra, G., Schloss, I., Mercuri, G., Laturnus, F. and Curtosi, A. (1994). Hydrography of Potter Cove, a small fjord-like inlet on King George Island, South Shetlands. Estuarine Coastal Shelf Sci. 38: 523-537.

Mann, K.H. and Lazier, J.R.N. (1991). Dynamics of Marine ecosystems. Biological-physical interactions in the oceans. Blackwell Scientific Publications, Oxford. 466 pp.

Nelson, D.M. and Smith, W.O. (1991). Sverdrup revisited: Critical depths, maximum chlorophyll levels, and the control of Southern Ocean productivity by the irradiance-mixing regime. Limnol. Oceanogr. 36(8): 1650-1661.

Schloss, I. (1997). Escalas temporo-espaciales de variabilidad del fitoplancton costero antártico. PhD Thesis. University of Buenos Aires.

Schloss, I., Ferreyra, G., Kocmur, S. and Longhi, L. (in press). Estudio de la tasa potencial de crecimiento del fitoplancton en Caleta Potter (Is. 25 de Mayo, Antártida). IV Jornadas de Inv. Antárticas, Buenos Aires, September 1997.

Schloss, I., Ferreyra, G., Curtosi, A., Klöser, H., Mercuri, G. and Pinola, E. (1997). Factors governing phytoplankton and particulate matter variation in Potter Cove, King George Island (Antarctica). En: Antarctic Communities, Battaglia, B., J. Valencia y D.W.H. Walton (eds.). Cambridge University Press. pp.135-141.

Sverdrup, H.U. (1953). On conditions for the vernal blooming of phytoplankton. Journal du Conseil, Conseil Permanent International pour l'exploration de la mer, 18: 287-295.

Phytoplankton Primary Production in Potter Cove, King George Island

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Despite that information available on phytoplankton primary production in the South Shetland Islands is scarce, magnitudes reported seem to be lower than those from other Antarctic coastal areas (see review in Smith et al., 1996). The goal of this research was to quantify phytoplankton primary production in Potter Cove, a shallow coastal environment in King George Island, South Shetland Islands, characterised by a profuse colonisation by benthic filter feeders. We also related the production results with key physical parameters.

Materials and methods

Two sampling stations were defined in Potter Cove, namely S1, in the inner and S2 in the outer cove (see Fig. 1 in Schloss et al., this issue). Between October 1991 and February 1992 16 oceanographic stations were performed, approximately one per week. Water samples were collected from a rubber boat with a 4.7 L Niskin bottle at five fixed depths (0, 5, 10, 20 and 30 m). Temperature was measured with an inversion thermometer, and salinity was determined with an induction salinometer Beckman RS9. Light was measured using a Kahlsico 268WA310 underwater radiometer. Chlorophyll-*a* was calculated following Strickland and Parsons (1972). 0.5 - 1 L of sea-water were filtered onto 0.45 mm Millipore filters, and photosynthetic pigments extracted during 24 h in cold and dark conditions with 90% acetone. Readings were made with a Hitachi Perkin Elmer UV-VIS 139 spectrophotometer. Quantification of cells was done on water samples after Utermöhl (1958) on neutralised formaline (4%) fixed samples. Samples for phytoplankton qualitative analysis were taken with a 20 μm mesh net. Samples were acid-cleaned for fine systematic determinations. Carbon content per cell was calculated after Strathmann (1967), measuring at least 200 cells. For less abundant taxa, published data from Sommer (1989) were used.

Primary production: For the determination of photosynthesis normalised to chlorophyll-*a* as a function of light intensity the photosynthetron method was used (Lewis and Smith, 1983): small water volumes were incubated during short periods, and ^{14}C assimilation was measured. 5 m depth water samples from both stations were placed in dark flasks after collection, and later 1 ml sub-samples were irradiated with 12 different light intensities in the photosynthetron during 30-40 minutes. A final activity of about 5 mCi ml^{-1} ^{14}C (bicarbonate) was added to each sample. Incubation irradiances were measured with a Li-Cor, LI-185B model sensor. Scintillation cocktail was added after the incubations (4 ml Aquasol), and analysed in a Beckman LSDIO100C scintillation counter. The photosynthetic capacity (P^B_m: μg C (μg Chlorophyll-*a*)$^{-1}$ h^{-1}), photosynthetic efficiency [α: μg C (μg Chlorophyll-*a*)$^{-1}$ h^{-1} (μE m^{-2} s^{-1})$^{-1}$] and the photoinhibition parameter [$ß^B$: μg C (μg Chlorophyll-*a*)$^{-1}$ h^{-1} (μE m^{-2} s^{-1})$^{-1}$] were calculated after Platt et al. (1980). A *t*-test for paired samples was used to compare S1 and S2 samples, as well as spring and summer samples.

Results and discussion

Vertical profiles of temperature, salinity and σ_t displayed the same pattern at S1 (inner cove) and S2 (outer cove) during the whole study period (Fig. 1). This defines some contrasting hydrographic characteristics between these two sites, one more influenced by terrigenous inputs (S1) with stronger vertical gradients in the above parameters than the other (S2). Such inputs carry a considerable amount of particles which may limit phytoplankton primary production via the reduction of light available for photosynthesis (Schloss et al., this issue; Varela, this issue).

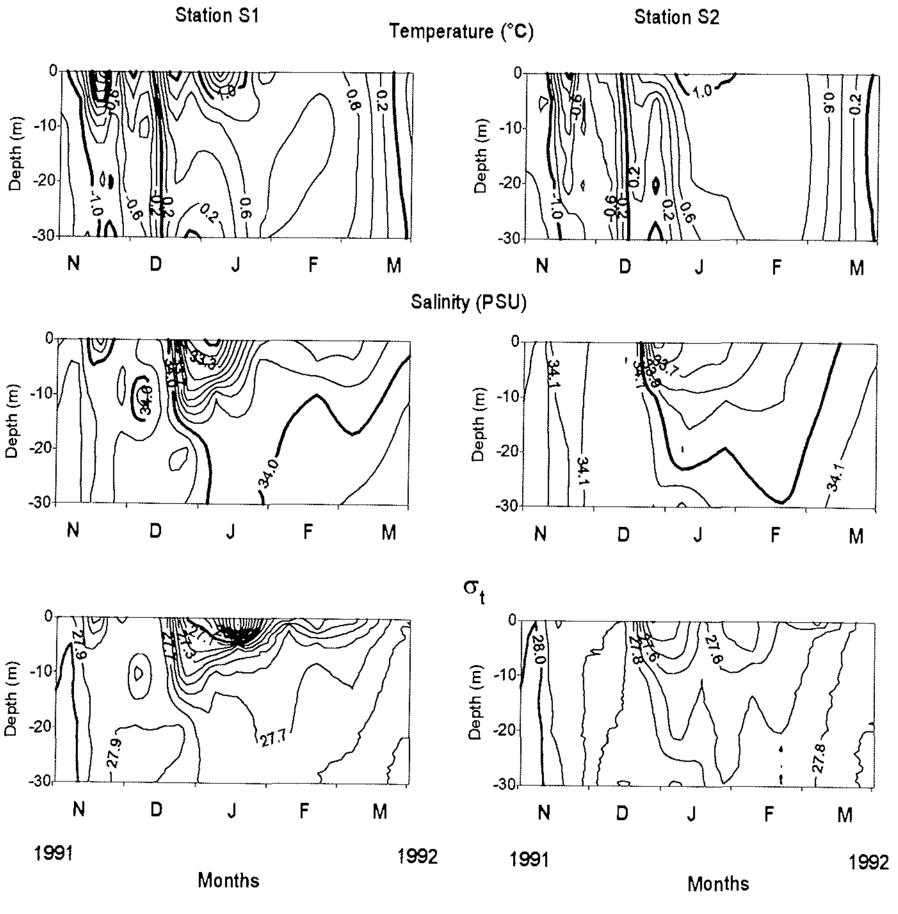

Figure 1: Some hydroographical parameters corresponding to the period when primary production was measured.

The highest cell concentration was observed in S1, on November 29, at 10 m. The species responsible for the maximum observed was *Thalassiosira antarctica*. However, considering phytoplankton carbon, the maximum was observed in S2, on November 26, at 20 m (26 mg C L^{-1}, for 5.6 x 10^4 cells L^{-1}), in an assemblage dominated by *Corethron criophilum*. Other quantitatively significant species were *Eucampia antarctica* and *Odontella weissflogii*. From December on, phytoplankton composition showed abundant phytoflagellates, and in occasions some microphytobenthic diatoms such as *Cocconeis spp.*, *Amphora spp.* and *Gyrosigma spp.*. Species from the genera *Navicula spp.*, *Licmophora spp.* and *Pseudogomphonema spp.* were also present. The physiological state of cells at the beginning of the study was good, based on the cell's shape and the presence of reproductive structures in species like *Corethron criophilum*. Endospores and auxospores were observed, the latter structure being abundant close to *Corethron criophilum*'s decline. Later on phytoplankton was scarce and no single species dominated the assemblages.

Values for the P *vs* I curve parameters are presented in Table 1. The average P^B_m was 1.049 μg C (μg Chlorophyll-*a*)$^{-1}$ h^{-1}, considering both stations, while α was 0,033 μg C (μg Chlorophyll-*a*)$^{-1}$ h^{-1} (μE m^{-2} s^{-1})$^{-1}$]. Photoinhibition was hardly observed at the light intensities used in the experiments (maximum corresponding to those irradiance values observed in the field at that time and 5 m depth, data not shown, see also Schloss et al., this issue).

Table 1: Parameters of the Photosynthesis vs Irradiance curves resulting from production measured experimentally with the photosynthetron.

Date	Station	$P^B s$	a	$ß^B$	P^B_{max}	I_{max}	I_k	I_b
Nov. 18, 1991	S1	1.364	0.016		1.313	433	82	
	S2	2.320	0.025	0.002	1.744	242	70	1160
Nov. 26, 1991	S1	0.279	0.012	0.000	0.266	112	22	2790
	S2	2.320	0.040	0.004	1.659	139	41	580
Nov. 29, 1991	S2	0.692	0.021	0.001	0.570	102	27	692
Dec. 4, 1991	S1	1.090	0.027	0.001	0.929	135	34	1090
	S2	0.552	0.028	0.000	0.539	111	19	5520
Dec. 8, 1991	S1	1.538	0.022		1.493	385	69	
Dec. 14, 1991	S1	0.263	0.060	0.001	0.242	18	4	263
	S2	0.999	0.065	0.001	0.922	64	14	999
Dec. 20, 1991	S1	1.388	0.087	0.003	1.192	54	14	463
	S2	1.064	0.027		1.038	221	38	
Dec. 30, 1991	S1	0.175	0.005	0.000	0.159	138	32	1750
	S2	2.103	0.020	0.003	1.347	214	67	701
Jan. 6, 1992	S1	2.570	0.056	0.001	2.349	186	42	2570
	S2	1.715	0.027	0.001	1.462	212	54	1715
Jan. 17, 1992	S1	2.321	0.080	0.001	2.170	127	27	2321
	S2	1.881	0.021	0.003	1.223	186	58	627
Jan. 26, 1992	S2	0.743	0.011	0.000	0.705	318	64	7430
Feb. 4, 1992	S2	0.553	0.011	0.000	0.525	237	48	5530
Feb. 14, 1992	S2	0.186	0.033	0.000	0.182	33	6	1860
Average		1.244	0.033	0.001	1.049	175	40	2114
Standard errors		0.173	0.005	0.000	0.139	23.7	5.0	480.1

The study period was divided in "spring" (from October 26 to December 20) and "summer" (from December 30 to February 14). Average P^B_m and α are presented in Table 2, for each station and each season. Although water column stratification was more marked in S1 than in S2 and in summer than in spring (Fig.1), from the paired *t*-test we could see that there were no significant differences neither between stations nor between seasons (p>0.05, Tab. 2).

Table 2: Averages and standard deviations (in parentheses) of a) the maximum assimilation values (P^B_{max}, in μg C (μg Chl.a)$^{-1}$ h^{-1}) and of b) the photosynthetic capacity (α, in μgC [(μg Chl.a) $^{-1}$ h^{-1})(μE m^{-2} s^{-1}) for stations S1 and S2 during spring and summer. Results obtained for the t-test for paired samples and their probabilities are indicated below.

a)
P^B_{max}

	S1	S2	Average
Spring	0,906 (±0,537)	1,079 (±0,521)	0,992 (±0,513) *t*=-0,57; p=0,58
Summer	1,559 (±1,216)	0,907 (±0,512)	1,125 (±0,800) *t*=0,89; p=0,46
Average	1,124 (±0,811) *t*=-0,94; p=0,43	0,993 (±0,501) *t*=-0,60; p=0,56	1,041 (±0,669) *t*=0,68; p=0,42 (S1-S2) *t*=-0,43; p=0,67 (spring-summer)

b)
α

	S1	S2	Average
Spring	0,037 (±0,030)	0,034 (±0,016)	0,036 (±0,023) *t*=0,21;p=0,84
Summer	0,047 (±0,038)	0,021 (±0,009)	0,029 (±0,024) *t*=1,18;p=0,35
Average	0,049 (±0,031) *t*=-0,39;p=0,72	0,027 (±0,014) *t*=1,83;p=0,11	0,033 (±0,023) *t*=1,19; p=0,26 (S1-S2) *t*=0,62; p=0,54 (spring-summer)

Thus the whole data set was combined to construct an "average" PI curve , for the estimation of the annual carbon production/budget in the cove (Fig. 2). In this case P^B_m was 1.091 μg C (μg Chlorophyll-*a*)$^{-1}$ h^{-1}, and α 0.029 μg C (μg Chlorophyll-*a*)$^{-1}$ h^{-1} (μE m^{-2} s^{-1})$^{-1}$], without any visible photoinhibition. The integrated chlorophyll-*a* and assimilated carbon values are shown in Table 3. Integrated water column production (from 0 to 30 m) was calculated using parameters derived from the production (P *vs* I) experiments. Daily integration was calculated computing day length (changing from 16.66 to 20 h). For the annual estimation, 6 months production (180 days) were considered, which is the mean time Potter Cove rested free of ice.

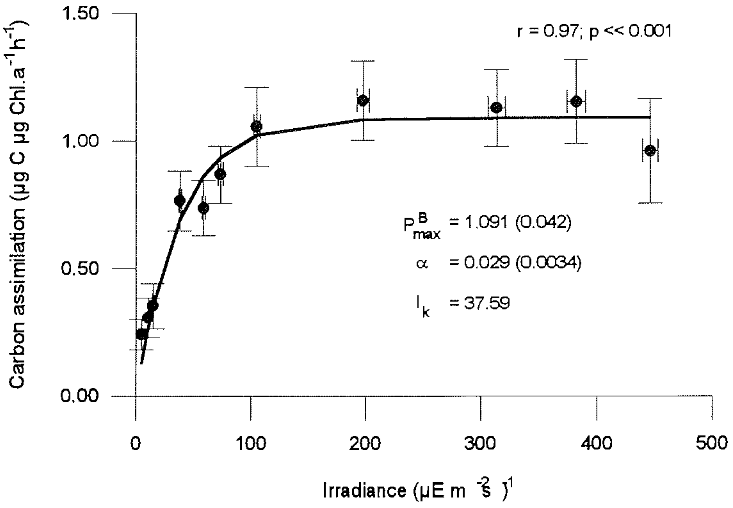

Figure 2: P vs I curve constructed with all the average light and production data. Vertical and horizontal bars as well as calculated values in brackets are standard errors of means. P^{B}_{max}: maximum estimated production (in µgC (µg Chl.a)$^{-1}$ h^{-1}), α, the photosynthetic capacity (in µgC [(µg Chl.a)$^{-1}$ h^{-1})] (µE m^{-2} s^{-1}) and I_k, the photoadaptation index (in µE m^{-2} s^{-1}).

Biomass and production values were somewhat lower than those described for the study area (Tab. 3), and significantly lower than values reported for the western Antarctic Peninsula or the South Orkney Islands. Applying the parameters calculated from the PI curve averaging all the production data to light and chlorophyll-*a* data from the other studied seasons (Schloss,1997),

Table 3: Some published chlorophyll and productivity data for coastal areas, during the spring-summer period. Data have been integrated to the depth indicated, or down to the euphotic depth. N: number of stations; SI: Signy Island; GS: Gerlache Strait.

Source	N	Depth (m)	Location	Integ. Chl.-*a* (mg m^{-2})	Integ. Daily Production (mg C m^{-2} d^{-1})
King George Island					
Hapter et al. (1983)	23	1 - 50	Admiralty Bay	27 - 170	150 - 1500
THIS STUDY	22	0-30	Potter Cove	7.07- 62.5	91 - 478
Unpublished data	50	0-30	Potter Cove	3.6 - 52.8	(estim.:236)
Other coastal areas					
Bienati et al. (1975)	7	0-15	Paradise Bay (GS)	154 - 265	2460- 3680
Whitaker (1982)	21	0-30	George Bay (SI)	1.9 - 605	4 - 4800
Holm-Hansen and Mitchell (1991)	347	0-750	W Bransfield Strait	13 - 175	70 - 3440
Helbling et al. (1995)	260	0-750	Elephant Island	5 - 630	50 - 930

the total production calculated was 236 mg C m^{-2} d^{-1}, very close to that calculated for the 1991/92 season, which was 259 mg C m^{-2} d^{-1}.In contrast to winter or autumn studies (Bightman and Smith, 1989), production was higher, indicating that conditions in Potter Cove are probably not so bad as in winter, but not as good as in other Antarctic coastal areas, preventing high production and biomass accumulation. The bad shape of algae observed microscopically during most of the summer may contribute to explain the low production values found. Productivity data presented here may be biased by season (there were just measurements in spring and summer). However, pigment concentration and light intensities during the rest of the year are very low, and probably don't contribute significantly to the overall productivity of the area. Investigations indicate that most Antarctic phytoplankton are adapted to handle low light conditions and are considered to be shade adapted (Sakshaug and Holm-Hansen, 1986). The low light intensity needed to saturate photosynthesis (I_k) determined in the present study coincides with this. In Potter Cove during the spring-summer period, not only limiting light conditions but also low stability in the water column, due to terrigenous inputs of light-absorbing particles and the high frequency of strong winds respectively, could help to explain the reduced photosynthetic rates and biomass accumulation of phytoplankton observed (Schloss et al., this issue).

Benthic organisms are ubiquitous in the soft sediments of the inner Potter Cove (Sahade et al.,1997). Densities of the most representative benthic organisms are such that water column production would probably not be sufficient to nourish them all. Ahn (1993), by studying the abundance and feeding of the bivalve *Laternula elliptica* in the neighbour Marian Cove, arrived to this same conclusion. Therefore, given the low pelagic primary production at Potter Cove, we suggest that othe sources like bacteria, macroalgal debris and probably microphytobenthos, via resuspension processes, would be the main energy source available for benthic filter feeders.

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References

Ahn, IY, (1993). Enhanced particle flux through the biodeposition by the Antarctic suspension-feeding bivalve *Laternula elliptica* in Marian Cove, King George Island. J. Exp. Mar. Biol. Ecol., 171:75-90

Bienatti, NL, Comes, RA and Spiedo, CH (1975). Producción primaria en aguas antárticas. Variación estacional y producción enriquecida en el ciclo de verano. Contribución del Instituto Antártico Argentino, n.193

Brightman, RI and Smith, WO, Jr (1989). Photosynthesis-irradiance relationships of antarctic phytoplankton during austral winter. Mar Ecol Prog Ser 53:143-151

Hapter, R, Wozniak, B and Dobrowolski, K (1983). Primary production in Ezcurra Inlet during the Antarctic summer of 1977/78. Oceanologia 15:175-184

Helbling, EW, Villafañe, VE and Holm-Hansen, O (1995). Variability of phytoplankton distribution and primary production around Elephant Island, Antarctica during 1990-1993, Polar Biol. 15(4):233-246

Holm-Hansen, O and Mitchell, BG (1991). Spatial and Temporal distribution of phytoplankton and primary production in the western Bransfield Strait region. Deep-Sea Res. 38, 961-980

Lewis, MR and Smith, JC (1983). A small volume, short incubation-time method for measurement of photosynthesis as a function of incident irradiance. Mar. Ecol. Prog. Ser, 13: 99-102

Platt, T, Gallegos, CL and Harrison, WG (1980). Photoinhibition of photosynthesis in natural assembalges of marine phytoplankton. J. Mar. Res. 38:687-701

Sahade, R, Tatián, M, Kowalke, J, Kuehne, S and Esnal, G (1997). Benthic faunal associations on soft bottom at Potter Cove, King George Island, Antarctica. Polar Biol. 19: 85-91

Sakshaug, E. and Holm-Hansen, O. (1986). Photoadaptation in Antarctic phytoplankton: variation in growth rate, chemical composition and P vs I curves. Journal of Plankton research, 8, 459-473

Schloss, IR (1997). Escalas temporo-espaciales de variabilidad del fitoplancton costero antártico. PhD Thesis, University of Buenos Aires, 209 pp.

Schloss, IR, Ferreyra, GA and Klöser, H. (this issue). Seasonal variation of the conditions for phytoplankton growth in Potter Cove.

Smith, RC, Dierssen, HM and Vernet, M (1996). Phytoplankton biomass and productivity in the western Antarctic Peninsula region. En: Ross, RM, Hofmann, EE and Quetin, LB (eds). Foundations for ecological research west of the Antarctic Peninsula. Antarctic research Series, Vol. 70:333-356

Sommer, U (1989). Maximal growth rates of Antarctic phytoplankton: Only weak dependence on cell size. Limnol Oceanogr, 34(6):1109-1112

Strathmann, R.R. (1967). Estimating the organic carbon content of phytoplankton from cell volume or plasma volume. Limnol Oceanogr 12:411-418

Strickland, JDH and Parsons, DR (1972). A practical handbook of seawater analysis. J. Fish. Res. Bd. Can Bull 167:1-310

Utermöhl H (1958). Zur Vervollkommung der quantitativen Phytoplankton-Methodik Mitt int Verein theor angew Limnol 9: 1-38

Varela, L (this issue) Hydrological behaviour of Matias and Potter Creeks

Whitaker, TM (1982). Primary production of phytoplankton off Signy Island, South Orkney, the Antarctic. Proc. R. Soc. Lond. B 214:169-189

Communities of Benthic Marine Algae at a Sheltered Site in Potter Cove, King George Island, South Shetlands, Antarctica

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Introduction

Studies on the Antarctic macroalgae began with the first expeditions in 1817 (reviewed in: Papenfuss 1964, Boraso & Quartino 1993, Wiencke 1996). Since that time a fair number of phycological studies on taxonomy, biogeography, ecophysiology and ecology have been performed up to now.

Benthic macroalgae are important contributors to primary production. They supply a lot of their biomass to benthic detrital food chains in the oceanic communities (Reichardt et al. 1985; Fischer & Wiencke 1992; Amsler et al 1995) and they contribute to the coastal food web directly (Brand 1980; Iken 1996).

Most research on sublittoral vegetation was restricted to qualitative descriptions of zonations (Skottsberg 1941; Lamb & Zimmerman 1977; Zielinski 1981; Klöser et al. 1994a). Only few publications present quantitative data on biomass and density of Antarctic benthic macroalgae. DeLaca & Lipps (1976) give some biomass data from macroalgal communities in Arthur Harbor. Miller & Pearse (1991) collected data on distribution, biomass, fertility and size of *Iridea cordata* and *Phyllophora spec.* as a function of depth in the impoverished vegetation of McMurdo Sound. Standing crop and cover of macroalgae at Signy Island was described by Brouwer et al. (1995). Quantitative data on algal cover are also provided by Amsler et al. (1995) from Arthur Harbor, and by Klöser et al. (1996) from Potter Cove, both by means of video documentations.

Studies of the benthic marine algal communities in Potter Cove (62° 14'S, 58° 40'W), King George Island, began in 1992. In 1994 the communities were documented by subaquatic video. The distribution of individual species of macroalgae and the composition of assemblages were compared with gradients of light availability, slope inclination, substrate, and exposition to turbulence and ice (Klöser et al. 1996). Instead of the classical three zones (ice-abraded sublittoral fringe, *Desmarestia* zone and *Himantothallus* zone) four zones were observed in the study area: a sublittoral fringe; an upper sublittoral with *Desmarestia menziesii* and *Ascoseira mirabilis* under strong turbulence; a central sublittoral with *Desmarestia anceps* under moderate turbulence; and a calm deeper sublittoral with *Himantothallus grandifolius.* This zonation is strongly modified by the impact of grounding icebergs. Specially the belt of *Desmarestia anceps* is suppressed in the central sublittoral of Potter Peninsula and replaced by a unique mixed assemblage of macroalgae with prevailing *Himantothallus grandifolius.* By that time a total of 34 species were recorded in the area.

At the same time a detailed study of abundance (biomass and density) and distribution of benthic marine algae was performed by an alternative method during three Antarctic summers in a sheltered site in Potter Cove (Figure 1). Square samples of benthic vegetation were collected in different depths by SCUBA diving. The aim of this study was to get data on macroalgal biomass and density during three antarctic summers, which by video analysis could not be acquired. An interesting question was, if the quantitative method used would yield the same grouping of species as in the detailed community analysis by video (Klöser et al. 1996).

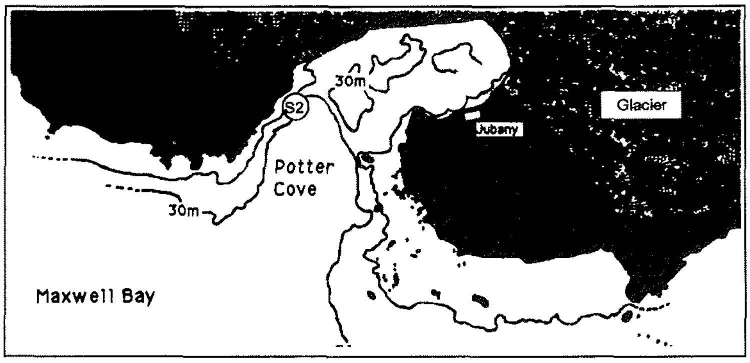

Figure 1: Map of the study area. S 2 "sheltered site".

Material and methods

The study was performed in Potter Cove (see above), a tributary inlet of Maxwell Bay, one of the two big fjords of the central South Shetland Islands. The study area is situated in the north-western coast at the mouth of the cove. Detailed descriptions of Potter Cove have been presented in earlier publications (Klöser et al. 1993, 1994a, 1994b, 1996).

Monthly samples were done by SCUBA diving from January to April of the years 1992, 1993, and 1994. A total of 144 samples were taken. The samples were performed on a transect perpendicular to the shore. The transect was repeated twelve times. On each repetition, twelve squares of 0.25 m^2 were sampled, of which three were situated at 5, 10, 15, and 20 m depth, respectively. At each given depth, a starting point was chosen at random. From this point, the three quadrates were positioned in a distance of 2 m from each other. All macroalgae inside the sample squares were removed from the substrate except the crustose coralline rhodophytes, which were not subject of this study. The substrate was visually classified into five types: I- solid rock, II- boulders > 50 cm, III- stones 20-50 cm, IV- pebbles 5-20 cm, V- gravel and sand < 5 cm.

Field samples were carried to the Dallmann laboratory at Jubany Station in large polyethylene bags as fast as possible. All algae were identified, counted and weighed. Voucher specimens were stored in a herbarium. Then, the material was fixed in 4% formaldehyde with seawater and transported to the laboratory in Buenos Aires. There, biomass, expressed as dry weight, was determined by drying the specimen at 60° C to constant weight.

Cluster analysis was employed to classify site groups. Bray-Curtis (1957), dissimilarity coefficient for quantitative data (density: number of individuals/m^2)

and group average method UPGMA (Sokal and Michener, 1958) were used. The original data matrix had many zeros, for this reason the three samples units corresponding to each depth were united, resulting in a 48 sample matrix. The relationship between the groups and the environmental factors were analysed with correspondence analysis (CA) (Benzecri, 1973) with additions by H. Gallelli (pers. comm.). Four depths (P 1 : 5 m; P 2 : 10 m; P 3 : 15 m; P 4 : 20 m) and the five mentioned substrate types (I to V) were considered. Fidelity of species to groups was determined using the χ^2 test.

Presence (P) was calculated as:

$$P = 100 . N_{ij} . N_j^{-1}$$

Nij = number of sample units of the **j** group where species **i** is present

Nj = number of sample units in the **j** group.

Results

In the particular study site 23 taxa were identified (Table I).

The Bray and Curtis index was used as dissimilarity coefficient for density data. The clusters were determined at the cut level corresponding to the largest distance between consecutive dichotomies (0.75) (Figure 2). This cut-off point on the cluster analysis gives a convenient number of groups making the data more manageable and easier to interpret. Three of the 48 sample units used were considered "outliers" (sample units: 9, 10, 37).

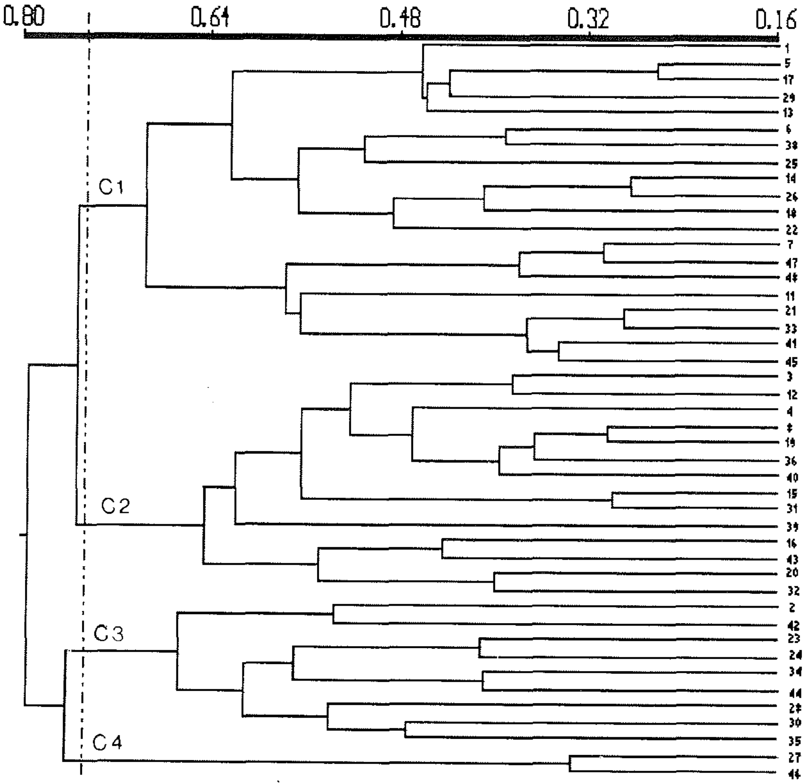

Figure 2 : Cluster diagram for the 48 samples units using density ("Outliers": 9,10,37)

Four clusters resulted (Figure 2); most of the sample units belonged to groups C1 and C2. The 80% of the samples of C1 corresponded to 5 and 10 m depth while in C2 the 100% of the sample were from 15 and 20 m depth.

The species composition of each group and presence index and fidelity (χ^2) significance are shown in Table I.

Table I: List of species sampled during this study. Presence index of species in clusters and species fidelity (*, significance > 95%) to each groups.

Species	**C 1**	**C 2**	**C 3**	**C 4**
Phaeophyta				
Adenocystis utricularis (Bory) Skottsberg 1907	100.0	0.0	0.0	0.0
Ascoseira mirabilis Skottsberg 1907	80.0	0.0	20.0	0.0
Desmarestia anceps Montagne 1842	45.8	20.8	*33.5	0.0
Desmarestia antarctica Moe et Silva 1989	16.7	0.0	*66.6	16.7
Desmarestia menziesii J. Agardh 1848	57.7	11.5	30.8	0.0
Himantothallus grandifolius (Gepp et Gepp) Zinova 1959	16.0	*56.0	28.0	0.0
Phaeurus antarcticus Skottsberg 1907	50.0	0.0	50.0	0.0
Rhodophyta				
Ballia callitricha (C. Agardh) Kützing 1843	57.1	42.9	0.0	0.0
aff. Callophyllis sp.	33.3	33.3	33.3	0.0
Curdiea racovitzae Hariot in De Wildeman 1900	*78.6	0.0	21.4	0.0
Georgiella confluens (Reinsch) Kylin 1956	50.0	27.8	16.7	5.5
Gigartina skottsbergii Setchell et Gardner 1936	*77.3	22.7	0.0	0.0
Gymnogongrus antarcticus Skottsberg 1953	100.0	0.0	0.0	0.0
Gymnogongrus turquetii Hariot 1907	50.0	50.0	0.0	0.0
Hymenocladiopsis crustigena Moe 1986	14.3	*71.4	14.3	0.0
Iridaea cordata (Turner) Bory 1826	*75.0	5.0	15.0	5.0
Kallymenia antarctica Hariot 1907	25.0	*62.5	12.5	0.0
Myriogramme mangini (Gain) Skottsberg 1953	57.2	21.4	21.4	0.0
Myriogramme smithii (Hook fil. et et Harvey) Kylin 1924	60.0	26.7	13.3	0.0
Palmaria decipiens (Reinsch) Ricker 1987	33.3	0.0	*55.6	11.1
Plocamium cartilagineum (Linné) Dixon 1967	48.7	33.3	15.4	2.6
Sarcodia montagneana (Hook fil. et Harvey) J.Agardh 1872	37.5	50.0	12.5	0.0
Sp A (O. Cryptonemiales)	25.0	50.0	25.0	0.0

In terms of fidelity, C1 is principally represented by *Curdiea racovitzae, Gigartina skottsbergii* and *Iridaea cordata*; C2 is characterised by *Himantothallus grandifolius, Hymenocladiopsis crustigena,* and *Kallymenia antarctica* and C3 is represented by *Desmarestia menziesii, Desmarestia antarctica and Palmaria decipiens.*

The relation of the groups resulting in the density cluster with depth and substrate was made using correspondence analysis (CA). Four depth categories and five types of substrate were considered. The first two axes explained 72% of the total variance in the data.

Figure 4 and Table II show that Cluster 1 is associated with rock, boulder and 5 m depth and in minor degree to 10 m and stone.

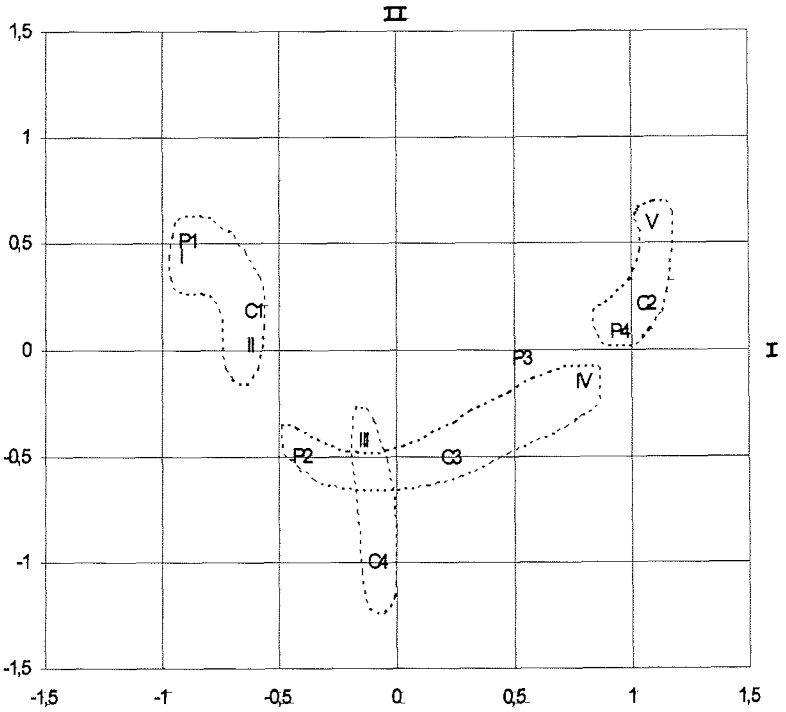

Figure 4: Correspondence analysis (Axes I and II). C1: cluster 1, C2: cluster 2, C3: cluster 3, C4: cluster 4. P1: 5 m, P2: 10 m, P3: 15 m, P4: 20 m. I: solid rock, II: boulder > 50 cm, III: stones 20-50 cm, IV: pebbles 5-20 cm, V: gravel and sand <5 cm.

Cluster 2 is strongly related to 20 m and gravel, and weaker with 15 m and pebble. Cluster 3 is associated with 10 m and pebbles, and in second place with boulder and 20 m. Cluster 4 is the smallest group in the density cluster analysis formed by only two samples corresponding to 10 and 15 m with stone substrate.

Table II: Conditional probabilities between clusters and environmental factors (substrate and depth). The conditional probabilities greater than the unconditional probability are in bold and they mean correspondence between both descriptors. Data are ranked on the first axe.

	5m	**Solid rock**	**Boulder**	**10m**	**Stones**	**15m**	**Pebble**	**20m**	**Gravel**
C1	**1000**	**1000**	**750**	545	455	250	91	83	143
C2	0	0	0	0	182	500	545	**667**	**857**
C3	0	0	250	**364**	182	167	**364**	250	0
C4	0	0	0	91	**182**	83	0	0	0

Table III shows the mean biomass value per individual at each depth. Taking into account the dominance, abundance and depth five groups of species resulted: Dominant species at different depths which include *Ascoseira mirabilis* and the three dominant species of Desmarestiales: *D. anceps*, *D. menziesii* and *Himantothallus grandifolius*; Species characteristic of shallow water; Abundant species at all depths; Characteristic species in 10 and 15 m and High abundance species at 5 and 20 m. This last group is formed by species opportunists of poor competitive abilities.

Table III: Mean biomass value per individual at each depth.(n:number of individuals, $\overline{X}$:mean, SD: standard deviation)

Species	**5 m**			**10 m**			**15 m**			**20 m**			**Description**
	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD	
A.mirabilis	19	150.08	290.41	2	19.58	12.03	0	–	–	0	–	–	Dominant species at different depths
D. anceps	12	286.99	412.51	18	441.54	1156.61	8	125.35	259.13	14	29.43	41.56	
D. menziesii	17	717.35	1246.34	37	262.83	732.55	6	290.21	637.17	10	14.91	22.88	
H.grandifolius	0	–	–	10	321.52	423.41	16	246.04	399.82	34	97.26	147.52	
A. utricularis	1	2.10	–	0	–	–	0	–	–	0	–	–	Species characteristic of shallow water
G. antarcticus	6	1.21	–	0	–	–	0	–	–	0	–	–	
C. racovitzae	20	40.93	72.83	4	30.08	14.71	5	1.11	1.23	0	–	–	
P. antarcticus	8	9.65	7.23	1	1.78	–	0	–	–	2	1.19	0.81	
I. cordata	30	2.60	1.94	14	2.46	3.77	5	2.74	2.23	1	0.01	–	
D. antarctica	11	26.35	40.31	37	34.18	48.42	11	7.34	12.83	7	6.39	3.97	Abundant species at all depths
G. skottsbergii	26	17.33	22.96	9	38.87	27.74	11	20.75	32.81	3	38.64	32.26	
B. callitricha	4	0.34	0.38	9	3.05	0.94	7	1.51	1.67	1	0.02	–	Characteristic species in 10 and 15 m
K. antarctica	2	26.43	0.63	10	4.77	3.68	10	27.48	27.68	9	9.76	9.80	
Sp A	0	–	–	4	26.19	0.50	3	26.62	12.3	0	–	–	
aff Callophyllis	0	–	–	4	6.27	1.84	4	17.35	2.26	0	–	–	
H. crustigena	0	–	–	5	10.31	1.63	6	25.59	15.14	2	14.24	9.79	
S. montagneana	0	–	–	6	18.27	1.87	6	12.12	10.23	0	–	–	
G. confluens	13	4.37	4.38	6	4.53	3.74	9	7.73	7.85	3	12.92	1.50	High abundance species at 5 and 20 m (opportunists of poor competitive abilities)
M. mangini	14	4.73	7.57	3	0.95	0.95	3	0.84	0.06	2	7.99	1.50	
M. smithii	7	109.27	9.73	4	6.68	0.91	3	4.20	0.41	3	39.62	11.09	
P. decipiens	12	4.81	0.99	18	2.31	4.15	14	2.92	4.84	23	6.39	5.92	
G. turquetii	4	5.36	2.68	0	–	–	4	19.86	18.87	1	65.71	–	
P. cartilagineum	34	3.49	6.82	14	5.33	5.31	35	5.33	15.47	30	22.18	35.26	

Discussion

In Potter Cove and the surrounding area a total of 62 species has been collected between 1992 and 1994 (Klöser et al. 1994a, 1996; Wiencke and Clayton, pers. comm). In this study only 23 species have been found. This is probably due to the restricted study area and to the exclusion of the 0 m level where it is common to find intertidal species like *Enteromorpha bulbosa* and *Porphyra endiviifolium*. The presence of *Adenocystis utricularis* and *Gymnogongrus antarcticus* was limited to very few samples. Thus, although they reached a high percentage in these few samples, they were not characteristic of their clusters. *A. utricularis* is usually found in the superior littoral belt of the cove, but we collected only one sample with individuals of this species, probably because we did not take samples of the upper first meters.

Additionally, the paucity of species may be explained by the fact, that the chosen site was a sheltered, well-vegetated location with strong preponderance of *Desmarestia sp.*, which is able to exclude other species by competition for light (Klöser et al. 1994a; 1996).

The community cluster analysis showed at Cluster 1 is associated with rock, boulder and 5 m depth and to less degree to 10 m and stone and corresponds principally to the forest of the two perennial *Desmarestia* species (*D. menziesii and D. anceps).*

C2 corresponded to the community dominated by *Himantothallus grandifolius* on gravel in 20 m and pebble in 15 m. This cluster agrees well with earlier findings (Klöser et al. 1993, 1996). C3 is a mixed assemblage with *Desmarestia anceps* and some species indicative of disturbance like the annual *Desmarestia antarctica* and *Plocamium cartilagineum.* It is associated with 10 m and pebbles. Hence this assemblage may mirror the scenario described earlier from Potter Cove, in which *Desmarestia spp.* germinate on stones which would not allow sufficient anchorage for the old and big *Desmarestia spp* plants, resulting in their removal by water turbulence (Klöser et al. 1994a, 1996). C4 is the smallest group in the density cluster formed by only two samples corresponding to 10 and 15 m with stone substrate, recolonization by *Desmarestia antarctica* and *Palmaria decipiens.*

A significant decrease of biomass at the 20 m level is observed in the majority of species, which may be due to reduced growth because of reduced illumination in that depth. This reduction in biomass is also observed in *Himantothallus grandifolius*, which usually is dominant in the deeper levels and frequently interpreted as specifically low-light adapted species. Our results may confirm the alternative concept, that optimal growth of *H. grandifolius* would take place in lower depths where it is excluded by competition of light (Klöser et al. 1994a,1996). The dominance of *H. grandifolius* in 20 m depth thus would be solely the consequence of the absence of the *Desmarestia spp.*

The present results and discussion are preliminary. At present, a more detailed and accurate statistical analysis of the data is under way. We suspect that a finer resolution of algal assemblages will be possible and enable us to identify and explain more thouroghfully the characteristic communities of this sheltered site.

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References

Amsler C.D., Rowley R.J., Laur D.R., Quentin L.B. and Ross R.M. (1995). Vertical distribution of Antarctic peninsular macroalgae: cover, biomass and species composition. Phycologia, 34 (5): 424-430.

Boraso de Zaixso A. and Quartino M.L. (1993). Estudios sobre algas marinas bentónicas en Argentina. Naturalia Patagónica, Cs. Biol. 1: 35-57.

Brand T.E. (1980). Trophic interactions and community ecology of the shallow marine benthos along the Antarctic Peninsula. Ph. D. thesis. Univ. Davis, California.

Bray J.R. and Curtis J.T. (1957). An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr., 27: 325-349.

Brouwer P.E.M., Geilen E.F.M., Gremmen N.J.M. and Van Lent F. (1995). Biomass, cover and zonation pattern of sublittoral macroalgae at Signy Island, South Orkney Islands, Antarctica. Bot. Mar., 38: 259-270.

DeLaca T.E. and Lipps J.H. (1976). Shallow-water marine associations, Antarctic Peninsula. Antarct. J. US, 11: 12-20.

Fischer G. and Wiencke C. (1992). Depth distribution and fate of macroalgae from the Antarctic peninsula region inferred from stable carbon isotope analysis. Polar. Biol., 12: 341-348.

Iken K. (1996). Trophische Beziehungen zwischen Makroalgen und Herbivoren in der Potter Cove (King George-Insel, Antarktis). Report on Polar Res. 201, 214 pp.

Klöser H., Ferreyra G., Schloss I., Mercuri G., Laturnus F. and Curtosi A. (1993). Seasonal variation of algal growth conditions in sheltered Antarctic Bays: the example of Potter Cove (King George Island, South Shetlands). J. Mar. Syst., 4: 289-301.

Klöser H., Mercuri G., Laturnus F., Quartino M.L. and Wiencke C. (1994a). On the competitive balance of macroalgae at Potter cove (King George Island, south Shetland) Polar Biol., 14: 11-16.

Klöser H., Ferreyra I., Schloss I., Mercuri G., Laturnus F. and Curtosi A. (1994b). Hydrography of Potter Cove, a small fjord-like inlet on King George Island (South Shetlands) Est. Coast Shelf Sci., 38: 523-537.

Klöser H., Quartino M.L. and Wiencke C. (1996). Distribution of macroalgae and macroalgal communities in gradients of physical conditions in Potter Cove, King George Island, Antarctica. Hydrobiologia, 333: 1-17.

Lamb I.M. and Zimmerman M.H. (1977). Benthic marine algae of the Antarctic Peninsula. Antarct. Res. Ser., 23: 130-229.

Miller K.A. and Pearse J.S. (1991). Ecological studies of seaweeds in McMurdo Sound, Antarctica. Amer. Zool., 31: 35-48.

Papenfuss G.F. (1964). Catalogue and bibliography of Antarctic and Subantarctic benthic marine algae. Am. Geophys. Union Antarct. Res. Ser., 1:1-76.

Reichardt W. and Dieckmann G. (1985). Kinetics and trophic role of bacterial degradation of macro-algae in Antarctic coastal waters. In W.R.Siegfried, P.R. Condy and R.M. Laws (eds), Antarctic nutrient cycles and food webs. Springer, Heidelberg, 115-122.

Skottsberg, C.J.F. (1941). Communities of marine algae in subantarctic and antarctic waters. Kongl. Svensk. Vet. Akad. Handl. 3. Ser., 19: 1- 92.

Wiencke C. (1996). Recent advances in the investigation of Antarctic macroalgae. Polar Biol., 16: 231-240.

Zielinski K. (1981). Benthic macroalgae of Admiralty Bay (King George Island, South Shetland Islands) and circulation of algal matter between the water and the shore. Pol. Polar Res., 2 : 71-94.

Biodiversity, life cycles and evolution of Antarctic macroalgae

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Present knowledge of the biodiversity of Antarctic benthic macroalgae and their distribution is still far from comprehensive. In 1964, Skottsberg estimated a species number of 96 (Table 1). In 1994, Clayton suggested that a more realistic number would be at least 120, our present compilation results in 141 species. In future, the number of species recorded for Antarctica will certainly increase as only a small proportion of the coastline has been explored and even brief periods of field research continue to yield new records, even in locations frequently visited by expeditions.

TABLE 1: Records of Antarctic seaweeds 1964 - 1998

	Chlorophyta		Phaeophyta		Rhodophyta		**Total**
	No. species	%	No. species	%	No. species	%	
Skottsberg	16	16.7	19	19.8	61	63.5	**96**
This study	24	17.0	30	21.3	87	61.7	**141**
% increase							**46.8**

For example, during a recent stay at Potter Cove we collected five species new to Antarctica, and four more from other islands of the South Shetlands and from the Antarctic Peninsula (Clayton et al. 1997). Three of these species [*Petalonia fascia* (O. F. Müller) Kuntze; *Enteromorpha intestinalis* (L.) Nees; *Rhodymenia subantarctica* Ricker] are new records for Antarctica, the others [*Chordaria linearis* (Hooker et Harvey) Cotton; *Halopteris obovata* (Hooker et Harvey) Sauvageau, *Acrosiphonia arcta* (Dillwyn) J. Agardh; *Enteromorpha compressa* (L.) Nees; *Bangia atropurpurea* (Roth) C. Agardh; *Porphyra plocamiestris* Ricker] have been reported only once, twice (or three times) before. Four of the nine species are known from sub-Antarctic islands and/or from southern South America and five species are more widely distributed in temperate waters. It is not known whether these newly recorded species are native to Antarctica or recent arrivals. However, the temperate affinities and cosmopolitan nature of *E. intestinalis, E. compressa* and *P. fascia* suggest the possibility of relatively recent introduction by ships or other vectors such as drifting wood. Since the early nineteenth century, ships have visited the South Shetland Islands which served for a long time as bases for sealers and whalers. Today the islands are visited regularly by both research and tourist vessels.

TABLE 2: Taxa of macroalgae within the Antarctic region including South Georgia

	families	genera	species
Rhodophyceae			**87**
Bangiales	2	3	5
Acrochaetiales	1	1	3
Nemaliales	1	1	1
Bonnemaisoniales	1	3	3
Corallinales	1	6	14
Palmariales	1	1	2
Hildenbrandiales	3	5	7
Gigartinales	7	12	18
Ahnfeltiales	1	1	1
Gracilariales	1	2	2
Rhodymeniales	1	2	2
Ceramiales	3	20	29
Phaeophyceae			**30**
Ectocarpales	3	5	5
Scytosiphonales	1	2	2
Chordariales	3	4	5
Dictyosiphonales	1	1	2
Scytothamnales	1	1	1
Syringodermatales	1	1	2
Sphacelariales	1	2	2
Dictyotales	1	1	1
Desmarestiales	1	3	7
Ascoseirales	1	1	1
Durvillaeales	1	1	1
Fucales	1	1	1
Chlorophyta			**24**
Ulvophyceae			**13**
Codiolales	4	4	8
Ulvales	1	2	5
Cladophorophyceae			**6**
Cladophorales	1	4	6
Bryopsidophyceae			**1**
Halimedales	1	1	1
Chlorophyceae			**3**
Chaetophorales	1	2	3
Pleurastrophyceae			**1**
Prasiolales	1	1	1
TOTAL	**48**	**94**	**141**

In view of predicted global climate changes, newly recorded algae may be considered as possible indicator organisms in studies monitoring environmental change. For example, the southern distribution limit of *R. subantarctica* is apparently set by the relatively high temperature demands for growth (Bischoff-Bäsmann & Wiencke 1996). This species grows optimally at 5-10 °C. At 0 °C, a temperature characteristic for King George Island, growth rates are strongly reduced, indicating that the species is here at or close to its southern distribution boundary.

In spite of the shown increase in the number of species of marine macroalgae recorded from Antarctica, the Antarctic marine algal flora is characterised by a low species richness compared to many temperate and tropical macroalgal floras. The Rhodophyceae comprise more than 60 % of the marine macroalgal flora of Antarctica with species of the Ceramiales, Gigartinales and Corallinales being most numerous (Table 2). About 40 % of the Antarctic marine flora is endemic, most species belonging to the Rhodophyceae. Endemic genera include *Gainia*, *Antarcticothamnion* (Rhodophyceae), *Lambia*, *Lola* (Chlorophyta), *Ascoseira*, *Cystosphaera*, *Himantothallus* and *Phaeurus* (Phaeophyceae).

The ecologically dominant and important sublittoral canopy algae are the Phaeophyceae *Himantothallus grandifolius* (A. et E. S. Gepp) Zinova, *Desmarestia anceps* Montagne, *D. menziesii* J. Agardh (Desmarestiales), *Cystosphaera jacquinotii* (Montagne) Skottsberg (Fucales) and *Ascoseira mirabilis* Skottsberg (Ascoseirales), all reaching lengths of up to several metres. Therefore, isolation and cultivation of Antarctic macroalgae (Clayton & Wiencke 1986) began with the life histories, vegetative and reproductive morphology of *Ascoseira mirabilis* (Clayton 1987, Clayton & Ashburner 1990, Müller et al. 1990) and of the Desmarestiales, *Desmarestia antarctica* Moe et Silva (Moe & Silva 1989; Wiencke et al. 1991), *Himantothallus grandifolius* (Wiencke & Clayton 1990) and *Phaeurus antarcticus* Skottsberg (Clayton & Wiencke 1990).

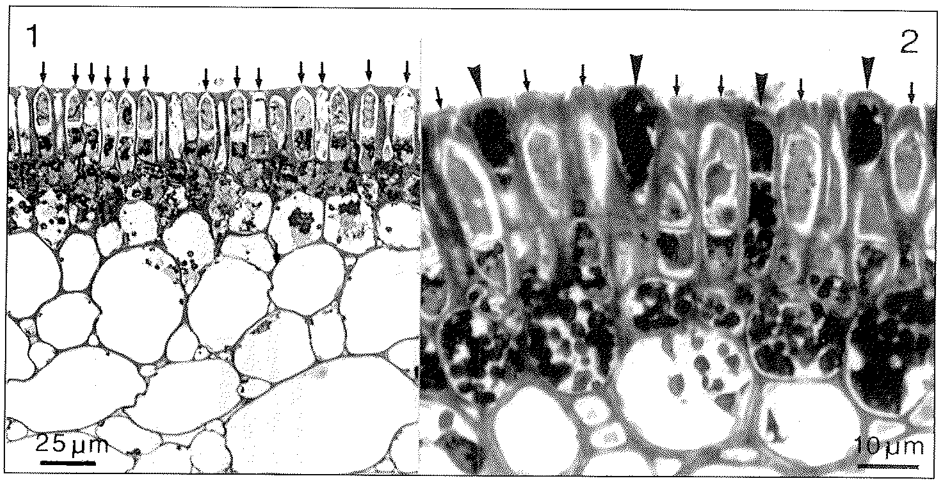
The order Desmarestiales is particularly interesting as species are distributed throughout the world in temperate and cold regions, but the generic diversity is greatest in Antarctica. Therefore, it was reasonable to assume that the order has its major evolutionary diversification in Antarctica. This prompted us to work further on the reproductive morphology, life history and development of the Antarctic species of the Desmarestiales in order to clarify evolutionary relationships within the order. The life history of the Desmarestiales is heteromorphic with microscopic, filamentous gametophytes and macroscopic, annual (e. g. *Phaeurus*, *D. antarctica*) or perennial (e. g. *Himantothallus*, *D. anceps* and *D. menziesii*) sporophytes. The gametophytes are monoecious (*D. antarctica* and many non-Antarctic species; Table 3) or dioecious (all other Antarctic species), reproduction is by oogamy. The sporophytes are terete (e. g. *Phaeurus*), more or less compressed (e. g. *D. menziesii*, *D. anceps*) or ligulate (e. g. *Himantothallus*, *D. antarctica*) and are formed by cortication of central and lateral axial filaments (e. g. Clayton & Wiencke 1990; Wiencke & Clayton 1990; Wiencke et al. 1991).

With respect to the reproductive morphology of the sporophytes (Table 3), *Phaeurus* is characterized by catenate sporangia, developing as filamentous outgrowths of the outer cortex (Clayton & Wiencke 1990). The other Antarctic species *D. antarctica*, *D. anceps* and *H. grandifolius* have sporangia developing together with 2 to 4 celled paraphyses to form an extensive elevated sorus (Wiencke & Clayton 1990; Wiencke et al. 1991, 1996). This type of sorus anatomy is not known from any non-Antarctic species of *Desmarestia*. The

Table 3: Morphological characters and upper survival temperatures (USTs) of Antarctic Desmarestiales and of Northern Hemisphere *Desmarestia aculeata*, compiled after Wiencke and Clayton (1990), Clayton and Wiencke (1990), Wiencke et al. (1991), Peters & Breeman (1992), Wiencke et al. (1994), Wiencke et al. (1995), Wiencke et al. (1996) and Peters et al. (1997).

	D. aculeata	*D. menziesii*	*D. anceps*	*D. antarctica*	*H. grandifolius*	*P. antarcticus*
Sporangia	on stalk cell, interspersed in vegetative cortex	on stalk cell, interspersed in vegetative cortex	on stalk cell, with paraphyses in extensive elevated sorus	on stalk cells, with paraphyses in extensive elevated sorus	on stalk cell(s), with paraphyses in extensive elevated sorus	catenate, arising from thallus surface
Branching of sporophyte	alternate, opposite branch initials aborted	mostly alternate, opposite branch initials mostly aborted	opposite, all branch initials developing	opposite, all branch initials developing	alternate to opposite, branch initials often aborted	opposite, all branch initials developing
sporophyte habit	compressed	compressed	compressed	ligulate	ligulate	terete
location of meristem in corticated sporophytes	above corticated part	above and in corticated part	in corticated part only	in corticated part only	in corticated part only	above corticated part
gametophytes	dioecious, eggs released, gametes formed in short and long days	dioecious, eggs not released, gametes formed in short days	dioecious, eggs not released, gametes formed in short days	monoecious, eggs not released, gametes formed in short and long days	dioecious, eggs mostly not released, gametes formed in short days	dioecious, eggs mostly released, gametes formed in short and days long days
USTs gametophytes (°C)	21.8 -24.5	16-17	13	no data	15-16	15

sporangium anatomy of *D. menziesii* (Fig. 1) is dissimilar to *D. anceps* (Fig. 2), *D. antarctica* and *H. grandifolius*, but the same as in the northern Hemisphere *D. aculeata* (Wiencke et al. 1995). These two species have stalked sporangia developing interspersed in the vegetative cortex. No elevated sorus is formed and no paraphyses are present.



Figs 1-2. Sporangia of *Desmarestia menziesii* (Fig. 1) and D. anceps (Fig. 2) Sporangia marked by arrows. Note the absence/presence of paraphyses (arrowheads) in D. *menziesii* / *D. anceps.*

Other characters also point to a relationship between *D. menziesii* and *D. aculeata* (Table 3). The branching pattern is in both species, in contrast to *D. antarctica* and *D. anceps*, mostly alternate, i. e. one of the opposite lateral branch initials formed in the juveniles is aborted during further development. Moreover, the intercalary meristem of corticated sporophytes is located in both species at least to some extent above the corticated part in contrast to *D. antarctica*, *D. anceps* and *H. grandifolius*. The adult sporophyte habit of *D. menziesii*, *D. aculeata* (and *D. anceps*) is compressed, but that of *D. antarctica* and *H. grandifolius* ligulate. On the other hand, eggs are released from the oogonia in *D. aculeata*, but (in most cases) not in *D. menziesii*, *D. anceps*, *D. antarctica* and *H. grandifolius*. Gamete formation is restricted to short days in *D. menziesii*, *D. anceps* and *H. grandifolius*, but not in *D. aculeata* and *D. antarctica*.

The upper survival temperatures (USTs, Table 3) of the gametophytes of *D. aculeata*, are relatively high (21.8 to 24.5 °C; Peters & Breeman 1992), the USTs of gametophytes of *D. menziesii*, *H. grandifolius* and *D. anceps* are 16 to 17 °C, 15 to 16 °C and 13 °C, respectively (Wiencke et al. 1994). None of these species would be able to cross the tropical warm water barrier as vegetative microthalli, neither today nor during glacial temperature decreases in the equatorial region (Peters & Breeman 1992; Wiencke et al. 1994). These results strengthen the hypothesis, that the Antarctic region is the evolutionary centre of the Desmarestiales and that an ancestral species similar to *D. menziesii* developed in Antarctica and has crossed the equator to form *D. aculeata*.

This hypothesis has been tested recently by analysing sequences of the nuclear ribosomal DNA internal transcribed spacers of 33 isolates from 20 species of Desmarestiales from the Northern and Southern Hemisphere (Peters et al. 1997). In the resulting molecular phylogeny (Fig. 3), which was rooted using *Arthrocladia villosa* (Hudson) Duby (Arthrocladiaceae) as outgroup, *P. antarcticus*, the Antarctic species of *Desmarestia*, and *H. grandifolius* formed a grade of basal branches in the Desmarestiaceae. The molecular tree supported the Antarctic origin of the Desmarestiaceae and the evolution of Northern Hemisphere *D. aculeata* from an Antarctic ancestor. Reproductive and ecophysiological traits were consistent with the molecular phylogeny (Figs 4, 5).

3

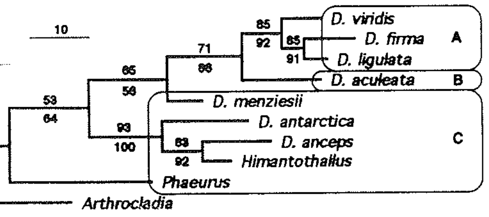
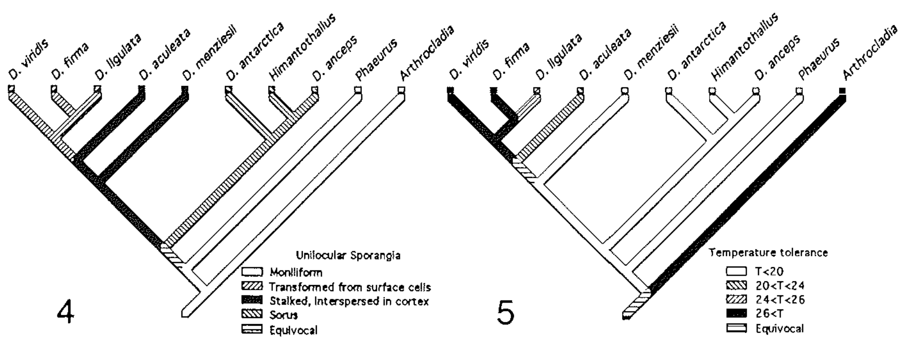


Fig. 3. Single most parsimonious phylogenetic tree for 10 species representing major subgroups of Desmarestiales, inferred from sequences of the nuclear ribosomal DNA internal transcribed spacer regions. A. Warm-temperate to coldwater species distributed on both Hemispheres. B. Warm-temperate to polar species of Northern Hemisphere. C. Antarctic endemics. The outgroup, *Arthrocladia villosa*, occurs in the warm-temperate region of the North Atlantic. Branch lengths indicate steps (scale = 10), numbers above and below branches are bootstrap percentages from 1000 replications for maximum parsimony and neighbour-joining analyses, respectively. Data from Peters et al. (1997), re- analysed.



Figs 4, 5. Evolution of characters in the Desmarestiales inferred from mapping of characters on the molecular tree. Fig. 5. Sporangial type. Fig. 6. Upper survival temperatures of gametophytes. In *Arthrocladia* assumed only because of occurrence in warm-temperate waters. After Peters et al. (1997).

In the Rhodophyta, the life history of *Porphyra endiviifolium* (A. et E. S. Gepp) Chamberlain, a species endemic to the Antarctic Peninsula region and South Georgia, was recently investigated (Wiencke & Clayton 1998). The species is characterised by an olive green colour and was originally described as *Monostroma endiviifolium*. The general pattern of the life history in *Porphyra* is heteromorphic, with macroscopic, foliose gametophytes alternating with a diploid microscopic, filamentous conchocelis phase. *P. endiviifolium* grows in summer in dense assemblages in high intertidal rocky habitats.

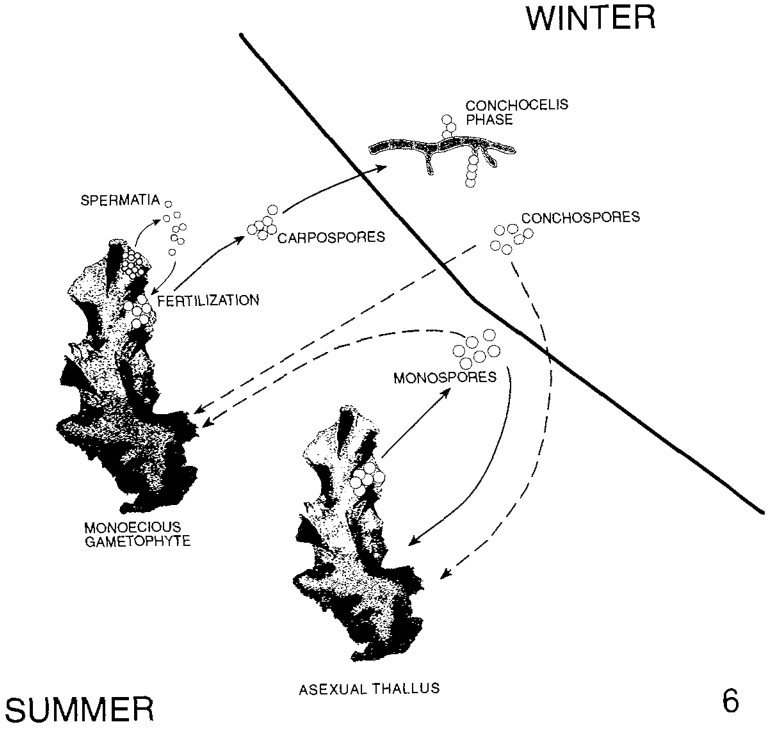


Fig. 6. Diagram of the life history and seasonal development of *Porphyra endiviifolium*. Continous / dotted lines represent observed / inferred developmental pathways (modified after Wiencke & Clayton 1998).

Field specimens were studied microscopically, prepared for electron microscopy and used to establish cultures. Wild populations consisted of two kinds of foliose thalli, morphologically similar but distinguished by their mode of reproduction, either sexual or asexual (Fig. 6). Carpospores from monoecious foliose gametophytes developed into conchocelis filaments in culture under fluctuating Antarctic daylengths. Under conditions simulating late winter-spring (10 h light per day) these developed conchospores that germinated and formed foliose macrothalli. Monospores from asexual foliose thalli developed directly into two different forms of foliose thalli. Only one of the cultured foliose morphotypes became fertile and produced asexual monospores.

The different morphological phases of the life history of *P. endiviifolium* exhibit different ecological strategies. The foliose phase of *P. endiviifolium* is opportunistic, develops during the Antarctic summer and is physiologically characterised as sun plant (Weykam et al. 1996), i. e. shows the characteristics of "season responders" (Wiencke 1996). We presume that asexual reproduction by monospores allows to enlarge these populations and also the further spread of the foliose phase during summer. In contrast, the conchocelis phase shows the characteristics of "season anticipators", species of algae that grow and reproduce in a strategic annual rhythm. The conchocelis phase is as shade plant adapted to overwintering and is more sensitive to high light stress than the porphyra phase (Hanelt et al. 1997).

References:

Bischoff-Bäsmann, B. & C. Wiencke (1996): Temperature requirements for growth and survival of Antarctic Rhodophyta. J. Phycol. 32: 525-535

Clayton M. N. (1989): Isogamy and a fucalean type of life history in the Antarctic brown alga, *Ascoseira mirabilis* (Ascoseirales, Phaeophyta). Bot. Mar: 30:447-506

Clayton, M. N. (1994): Evolution of the Antarctic marine benthic algal flora. J. Phycol. 30: 897-904

Clayton, M. N & C. M. Ashburner (1990): The anatomy and ultrastructure of "conducting channels" in *Ascoseira mirabilis* (Ascoseirales, Phaeophyeae). Bot. Mar. 33: 63-70

Clayton, M. N. & C. Wiencke (1986): Techniques and equipment for culturing Antarctic benthic marine algae, and for preparing specimens for electron microscopy. Ser. Cient. INACH 34: 93-97

Clayton, M. N. & C. Wiencke (1990): The anatomy, life history and development of the Antarctic brown alga *Phaeurus antarcticus* (Desmarestiales). Phycologia 29: 303-315

Clayton, M. N., C. Wiencke & H. Klöser (1997): New records of temperate and sub-Antarctic marine benthic algae from Antarctica. Polar Biol. 17: 141-149

Hanelt, D, B. Melchersmann, C. Wiencke & W. Nultsch (1997): Effects of high light stress on photosynthesis of polar macroalgae in relation to depth distribution. Mar. Ecol. Progr. Ser. 149: 255-266

Müller, D. G., R. Westermeier, A. Peters & W. Boland (1990): Sexual reproduction of the Antarctic brown alga *Ascoseira mirabilis* (Ascoseirales, Phaeophyceae). Bot. Mar. 33: 251-255

Peters, A. F.& A. M. Breeman (1992): Temperature responses of disjunct temperate brown algae indicate long-distance disposal of microthalli across the tropics. J. Phycol. 28: 428-438

Peters, A. F., M. J. H. van Oppen, C. Wiencke W. Stam & J. L. Olsen (1997): Phylogeny and historical ecology of the Desmarestiales (Phaeophyceae) support a Southern Hemisphere origin. J. Phycol. 33: 294-309

Skottsberg, C. J. F. (1964): Antarctic phycology. Comptes rendues Premier Symposium Biologie Antarctique, Paris 1962, Hermann, Paris, pp 147-154

Weykam G., I. Gómez, C. Wiencke, K. Iken & H. Klöser (1996): Photosynthetic characteristics and C:N ratios of macroalgae from King George Island (Antarctica). J. Exper. Mar. Biol. Ecol. 204: 1-22

Wiencke, C. (1996): Recent advances in the investigation of Antarctic macroalgae. Polar Biol. 16: 231-240

Wiencke, C. & M. N. Clayton (1990): Sexual reproduction, life history and early development in culture of the Antarctic brown alga *Himantothallus grandifolius* (Desmarestiales, Phaeophyceae). Phycologia 29: 9-18

Wiencke, C. & M. N. Clayton (1998): The life history of *Porphyra endiviifolium* from the South Shetland Islands, Antarctica. Polar Biol. (in press)

Wiencke, C., M. Clayton & C. Langreder (1996): Life history and seasonal morphogenesis of the endemic Antarctic brown alga *Desmarestia anceps* Montagne. Bot. Mar. 39: 435-444

Wiencke, C., M. N. Clayton & D. Schulz (1995): Life history, reproductive morphology and development of the Antarctic brown alga *Desmarestia menziesii* J. Agardh. Bot. Acta 108: 169-276

Wiencke, C., U. Stolpe & H. Lehmann (1991): Morphogenesis of the brown alga *Desmarestia antarctica* cultivated under seasonally fluctuating Antarctic daylengths. Ser. Cient. INACH 41: 65-78

Wiencke, C., I. Bartsch, B. Bischoff, A. F. Peters & A. M. Breeman (1994): Temperature requirements and biogeography of Antarctic, Arctic and amphiequatorial seaweeds. Bot. Mar. 37, 247-259

Life strategy of Antarctic macroalgae

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Macroalgae are conspicuous components of the Antarctic littoral communities Klöser et al. 1996) and account for an important fraction of the primary productivity in shallow coastal systems. Since the early descriptive surveys phycologists outlined the surprising ability of Antarctic macroalgae to grow under very harsh environmental conditions. However, ecophysiological studies focussing on life strategy, especially adaptations to low temperature and seasonally fluctuating light regime, began relatively late. Following isolation and culture of individual species in the laboratory during the eighties and early nineties, aspects such as growth and the life-history of various species were intensively addressed (reviewed in Wiencke 1996). In general, growth of some endemic Antarctic macroalgae is restricted to temperatures around 0 up to 5 (-10) °C, values far lower than that reported for cold-temperate species (Wiencke and tom Dieck 1989, 1990, Bischoff and Wiencke 1996). Likewise, light requirements for completion of the life cycle of several species are very low, and in many taxa, reproduction events and growth of early stages take place under dim light in winter (Wiencke 1990a,b, 1996). Particularly interesting was the finding that vegetative growth of many species is strongly governed by seasonal changes in daylengths, an important feature in the life strategy of these organisms (Wiencke 1990a,b).

The studies in the framework of the Argentinian-German Cooperation Program were undertaken to expand the knowledge on physiological processes involved in the life strategy of these plants. Thus, the existing information on the interactions between light environment and photosynthetic performance and organic composition of macroalgae, with special emphasis on morpho-functional relations, was considerably enlarged.

Photosynthesis as a function of thallus structure and development

Morpho-functional relations in Antarctic macroalgae have been basically studied in large brown algae. Perennial species such as *Ascoseira* or *Himantothallus* attain a thallus length of several meters, and are characterized by a complex structural organization. *In Ascoseira mirabilis*, the strap like-lamina resembles closely that of *Laminaria* species and elongates from an intercalary meristem located at the lamina basis. The growth activity starts in late winter-spring and leads to a differential biomass allocation along the thallus (Gómez et al. 1995a). The result is a gradient in tissues of different age and physiological features along the lamina. O_2-based net photosynthetic capacity (P_{max}) in this species is low in young, meristematic lamina regions, increases in the middle and declines again towards the distal regions. Measurements of light ^{14}C-fixation show a similar intra-thallus pattern, however, C fixation in the dark (the so-called light independent C-fixation) increases gradually towards the distal regions of the lamina (**Fig. 1**), contrasting with results reported for *Laminaria* species (Küppers and Kremer 1978). This pattern is related to ontogenetic development, i.e. photosynthesis increases with development up to a maximum and then decreases with further ageing. Interestingly, such a pattern of photosynthesis does not change with age of plants, but the overall rates decrease with age and size of the whole thallus (Gómez et al. 1996). These findings suggest that the activities of the Calvin cycle enzyme ribulose 1,5-bisphosphate carboxylase-oxygenase (RUBISCO), responsible for light C-fixation, and the phosphoenolpyruvate carboxykinase (PEP-CK), involved in b-carboxylation, are differentially distributed along the thallus in *Ascoseira*.

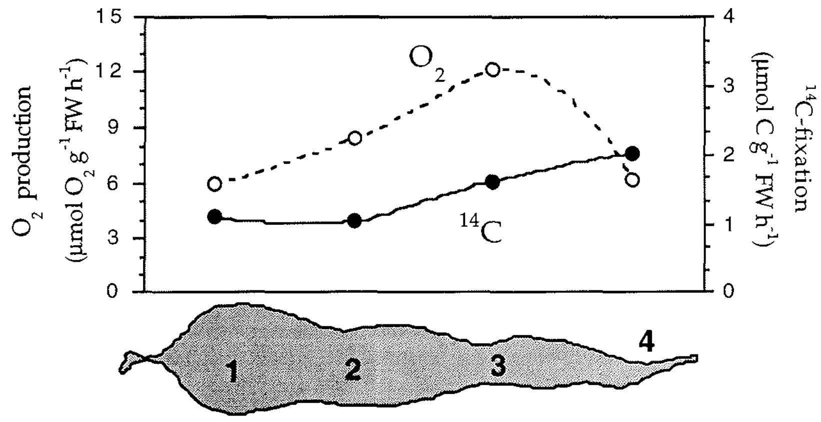

Fig. 1. Longitudinal profiles of O_2 production (net P_{max}) and light independent C-fixation (^{14}C) along the blade in *Ascoseira mirabilis*. Re-drawn from Gómez et al. (1995a).

Photosynthetic performance and heteromorphic life-history.

The brown algal order Desmarestiales shows an alternation of generations, with large terete diploid sporophytes and small filamentous gametophytes. The different stages in the life-history of these species are strongly determined by the light conditions: e.g. gametogenesis of several Desmarestiales such as *Himantothallus grandifolius* and *Desmarestia anceps* is restricted to the winter season under daylengths below 9 h and irradiances not exceeding 10 to 13 μmol photon m^{-2} s^{-1} (Wiencke 1990a, 1996, Wiencke et al. 1996). Fertilization and growth of early stages of sporophytes take also place during low light and adult sporophytes grow during late winter-spring conditions (Wiencke et al. 1991, 1995). Gametophytes and sporophytes are physiologically different as has been shown in *D. menziesii*. Gametophytes are characterised by a higher photosynthetic capacity (P_{max}), dark respiration and photosynthetic efficiency at limiting irradiances (α) and lower light saturation (I_k) for photosynthesis than adult sporophytes (Gómez and Wiencke 1996, **Fig. 2**).

Taking into account these findings and the light absorption characteristics of each developmental stage it is now possible to define a morpho-functional concept: growth of gametophytes and uncorticated sporophytes is favoured in winter in virtue of their filamentous organisation, high assimilatory pigment content per biomass, high area/volume ratio and low proportion of non-photosynthetic tissues. Thus, the "shade adaptation" of gametophytes of the Desmarestiales allows the algae to survive, reproduce and recruit under conditions unfavourable for large sporophytes, which require comparatively higher photon fluence rates for photosynthesis and growth.

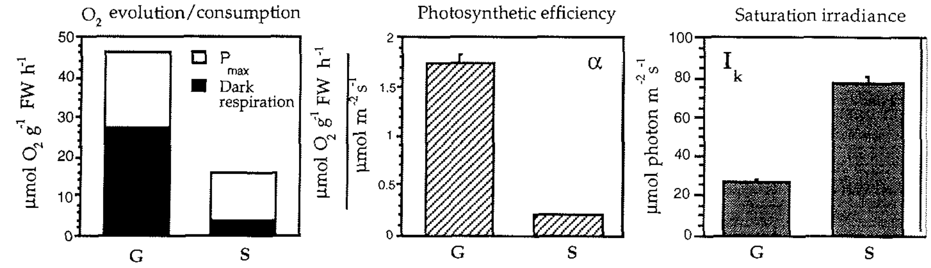

Fig. 2. Photosynthetic parameters and respiration of gametophytes (G) and sporophytes (S) of *Desmarestia menziesii.* Re-drawn from Gómez and Wiencke (1997).

Seasonal variations in growth, photosynthesis and contents of organic compounds in Antarctic macroalgae.

The question whether growth of Antarctic macroalgae responds primarily to seasonal changes in light intensity or to daylengths was studied in laboratory experiments using seasonally fluctuating daylength mimicking the regimes in the Antarctic (Wiencke 1990a, b, 1996). In winter, algae receive light for approximately 4-5 h whereas during summer daylengths extend up to 20 h. One growth strategy is based on the utilization of high irradiances in late spring-summer: littoral green algae such as *Enteromorpha bulbosa* and *Acrosiphonia arcta* or the upper sublittoral red alga *Iridaea cordata* are „season responders" showing increased biomass formation during November and December (Wiencke 1990b, Weykam 1996). In contrast, other species, mostly brown and red algae, are „season anticipators" starting their frond elongation already in late winter-spring when daylengths are between 5 and 7 h d^{-1} (Wiencke 1990a,b, Weykam and Wiencke 1996, Gómez et al. 1996, Gómez and Wiencke 1997).

The seasonal biomass formation in Antarctic macroalgae is linked to changes in photosynthetic performance and respiratory activity. This has been demonstrated in culture material of the red algae *Palmaria decipiens* and *Iridaea cordata* (Weykam 1990, Weykam and Wiencke 1996) and the brown algae *Ascoseira mirabilis* and *Desmarestia menziesii* (Gómez et al. 1995b, Gómez and Wiencke 1997). For example, in *Desmarestia menziesii* photosynthetic capacities (net P_{max}) and efficiencies (α) and specific growth rates increase strongly during late winter-spring and decline towards summer (**Fig. 3**). Although seasonal variations in compensation (I_c) and saturation (I_k) points have been reported for some species, light requirements for photosynthesis are characteristically low throughout the year, an adaptation to the prevailing low irradiances in the Antarctic (Weykam et al. 1996). Interestingly, even during prolonged darkness, the photosynthetic apparatus remains intact as demonstrated in *Iridaea cordata*, a "season responder" species, which is able to use any incoming light that reaches the alga in winter (Weykam 1996, Weykam et al. 1997). In contrast, *Palmaria decipiens* does not mantain a functional photosynthetic apparatus during darkness in winter. Rather, formation of new blades in late winter is dependent on remobilisation of storage compounds (see below) (Weykam 1996, Weykam et al. 1997).

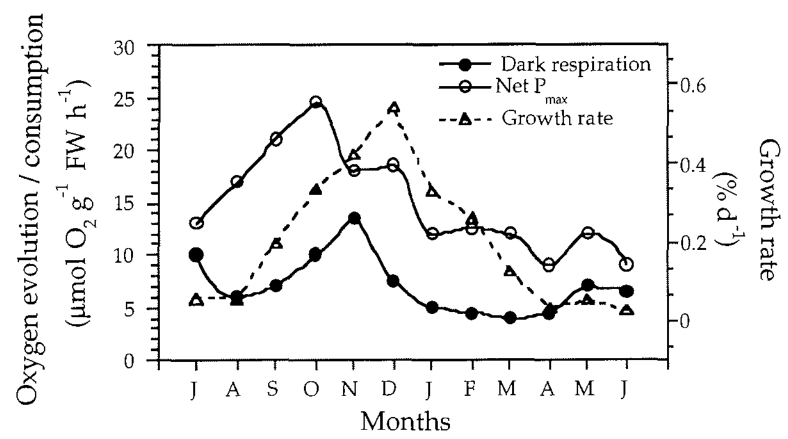

Fig. 3. Seasonal changes in net photosynthesis (P_{max}), dark respiration and growth rates of *Desmarestia menziesii* cultivated under a simulated Antarctic light regime. Taken from Gómez and Wiencke (1997)

Growth in late winter-spring is strongly dependent on the metabolic balance between C assimilation and dissimilation through dark respiration. During this period dark respiration can increase accounting for a great fraction of gross photosynthesis (Gómez 1997). Under light limited conditions remobilisation of reserve carbohydrates are mechanisms active in Antarctic macroalgae to support growth and other physiological processes when light is limited. In the red algae *Palmaria decipiens* and *Iridaea cordata*, Floridean starch content decreases while growth and photosynthetic activity are enhanced in late winter - spring (Weykam 1996). In the brown algae *Ascoseira mirabilis* and *Desmarestia menziesii*, seasonal photosynthetic activity is correlated to changes in mannitol and laminaran contents (Gómez and Wiencke 1998, Gómez et al. 1998). In *Ascoseira*, organic compounds are most problably transported in special conducting channels (Clayton and Ashburner 1990, Gómez and Wiencke 1998).

In general the data summarized here indicate that seasonal variation in daylength is the main factor governing productivity and seasonal development of Antarctic macroalgae. Further studies primarily focused on enzyme activities of specific metabolic processes, carbon and nitrogen budgets have urgently to be studied in order to understand the complex biological processes in these key organisms in Antarctic coastal waters.

References

Bischoff-Bäsmann, B. and Wiencke, C. (1996). Temperature requirements for growth and survival of Antarctic Rhodophyta. J. Phycol. 32: 525-535.

Clayton, M.N. and Ashburner, C.M. (1990). The anatomy and ultrastructure of „conducting channels" in *Ascoseira mirabilis* (Ascoseirales, Phaeophyceae). Bot. Mar. 33: 63-77.

Gómez, I. (1997). Life-strategy and ecophysiology of Antarctic macroalgae. Reports Polar Res. 238: 1-99.

Gómez, I. and Wiencke, C. (1996). Photosynthesis, dark respiration and pigment contents of gametophytes and sporophytes of the Antarctic brown alga *Desmarestia menziesii*. Bot. Mar. 39: 149-157.

Gómez, I. and Wiencke, C. (1997). Seasonal growth and photosynthetic performance of the Antarctic macroalga *Desmarestia menziesii* (Phaeophyceae) cultured under fluctuating Antarctic daylengths. Bot. Acta 110: 25-31.

Gómez, I. and Wiencke, C. (1998). Seasonal changes in C, N and major organic compounds, and their significance to morpho-functional processes in the endemic Antarctic brown alga *Ascoseira mirabilis*. Polar Biol. 19: 115-124

Gómez, I., Thomas, D. N and Wiencke, C. (1995a). Longitudinal profiles of growth, photosynthesis and light independent carbon fixation in the Antarctic brown alga *Ascoseira mirabilis*. Bot. Mar. 38: 157-164.

Gómez, I., Wiencke, C. and Weykam, G. (1995b). Seasonal photosynthetic characteristics of *Ascoseira mirabilis* (Ascoseirales, Phaeophyceae) from King George Island, Antarctica. Mar. Biol. 123: 167-172.

Gómez, I., C. Wiencke and D.N. Thomas (1996). Variations in photosynthetic characteristics of the Antarctic marine brown alga *Ascoseira mirabilis* Skottsberg in relation to age and size. Eur. J. Phycol. 31: 167-172.

Gómez, I., Weykam, G. and Wiencke, C. (1998). Seasonal photosynthetic metabolism and major organic compounds in the marine brown alga *Desmarestia menziesii* from King George Island (Antarctica). Aquatic Bot. (In press).

Klöser, H., Quartino, M.L. and Wiencke, C. (1996). Distribution of macroalgae and macroalgal communities in gradients of physical conditions in Potter Cove, King George Island, Antarctica. Hydrobiologia 333: 1-17.

Küppers, U. and Kremer, B. P. (1978). Longitudinal profiles of carbon dioxide fixation capacities in marine macroalgae. Plant Physiol. 62: 49-53.

Weykam, G. (1996). Photosynthetic characteristics and life-strategies of Antarctic macroalgae. Reports Polar Res. 192: 1-132.

Weykam, G. and Wiencke, C. (1996). Seasonal photosynthetic performance of the endemic Antarctic red alga *Palmaria decipiens* (Reinsch) Ricker. Polar Biol. 16: 357-361.

Weykam, G., Gómez, I., Wiencke, C., Iken, K. and Klöser, H. (1996). Photosynthetic characteristics and C/N ratios of macroalgae from King George Island (Antarctica). J. Exp. Mar. Biol. Ecol. 204: 1-22.

Weykam, G., Thomas, D. N. and Wiencke, C. (1997). Growth and photosynthesis of the Antarctic red algae *Palmaria decipiens* (Palmariales) and *Iridaea cordata* (Gigartinales) during and following extended periods of darkness. Phycologia 36: 395-405.

Wiencke, C. (1990a). Seasonality of brown macroalgae from Antarctica - a long-term culture study under fluctuating Antarctic daylengths. Polar Biol. 10: 589-600.

Wiencke, C. (1990b). Seasonality of red and green macroalgae from Antarctica- a long-term culture study under fluctuating Antarctic daylengths. Polar Biol. 10: 601-607.

Wiencke, C. (1996). Recent advances in the investigation of Antarctic macroalgae. Polar Biol. 16: 231-240.

Wiencke, C. and Dieck, I. tom (1989). Temperature requirements for growth and temperature tolerance of macroalgae endemic to the Antarctic region. Mar. Ecol. Prog. Ser. 54: 189-197.

Wiencke, C. and Dieck, I. tom (1990). Temperature requirements for growth and survival of macroalgae from Antarctica and Southern Chile. Mar. Ecol. Progr. Ser. 59: 157-170.

Wiencke, C., Clayton, M.N. and Schulz, D. (1995). Life history, reproductive morphology and development of the Antarctic brown alga *Desmarestia menziesii* J. Agardh. Bot. Acta 108: 201-208.

Wiencke, C., Clayton, M. and Langreder, C (1996): Life history and seasonal morphogenesis of the endemic Antarctic brown alga *Desmarestia anceps* Montagne. Bot. Mar. 39, 435-444

Wiencke, C., Stolpe, U. and Lehmann, H. (1991): Morphogenesis of the brown alga *Desmarestia antarctica* cultivated under seasonally fluctuating Antarctic daylenghts. Ser. Cient. INACH 41, 65-78

Habitats and distribution patterns of benthic diatoms in Potter Cove (King George Island, Antarctica) and its vicinity

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Diatoms can be used as tracers in studies on hydrography, sedimentation dynamics and transfer of organic matter in the marine food webs. In Antarctic coastal ecosystems, poor development of pelagic diatoms (Warnke *et al.* 1973; Platt 1979; Hapter *et al.* 1983; Schloss *et al.*, this issue) but important contributions of suspended benthic diatoms to the phytoplankton have been frequently observed (Krebs 1983; Berkman *et al.* 1986; Gilbert 1991a, b; Ahn *et al.* 1994; Klöser et al. 1994b; Schloss *et al.* this issue). Antarctic benthic diatoms are assumed to provide an important food source for benthic as well as pelagic animals. This study gives details on habitats and distribution of benthic diatoms of Potter Cove.

MATERIAL AND METHODS

Benthic diatom communities were sampled during 3 southern summers (December 1991 - February 1992, November 1992 - February 1993, and September 1993 - February 1994) in Potter Cove, King George Island. A variety of different potential habitats for benthic diatoms were collected by hand in the intertidal at Peñon Uno and, by SCUBA diving, in the sublittoral, down to 30m (Table 1). The samples were stored in separate flasks in seawater and taken to the laboratory as soon as possible, usually within 2 hours. They were analysed alive on the same day, using a microscope fitted with Nomarski differential interference contrast.

In an initial investigation, those diatom taxa were defined, which could savely be identified live at 200-fold magnification (Tab. 2). This was done by comparing living and acid-cleaned material from the same sample. Afterwards, the relative abundances of the identifiable taxa were estimated in fresh samples using a five step scale: 0 = never observed, 1 = few cells, less than 5% of the area covered in the microscopic image; 2 = between 5 and 25% covered; 3 = 25 to 50% covered; 4 = 50 to 75% covered; 5 = more then 75% covered.

Data from each type of substrates listed in Table 1 were pooled. The highest observed score for the abundance of the different diatom species in each habitat category was then used for a crosswise cluster analysis: firstly, habitat categories were clustered according to their diatom assemblages. Then, abundances of individual diatom species over all habitat categories, i. e. diatom distribution patterns, were clustered. Both calculations were performed with the Bray-Curtis-Index and the Unweighted Pair Group Method (Bakus 1990). In order to avoid confusion, the term 'habitat cluster' (HC) is used for the results of the first cluster analysis, and the term 'diatom distribution cluster' (DDC) for those of the second.

Although on a given type of habitat regularly the same assemblage of species was found during all three summers, the same habitat has also frequently been found more or less denuded, with the most characteristic species then being absent. These cases obscured patterns of diatom-habitat relationships, as it was not readily evident whether a poorly colonized habitat would be constantly devoid of significant diatom colonization or only temporarily disturbed and recolonized again later. In order to compensate for this, the highest abundance score of a diatom in each habitat category was used as a statistical basis, although this procedure overemphasizes

Table 1: List of abbreviations representing potential benthic diatom habitats. Substrates with an asterisk were found to be devoid of diatoms and therefore were ommitted from further consideration. Species names in this table refer to macroalgae, if not stated otherwise.

Samples from intertidal sites, which fall dry during low tide:	
FEA	filamentous eulittoral algae (*Urospora penicilliformis* (Roth) Areshoug, 1866, *Ulothrix* sp., *Bangia atropurpurea* (Roth) C.Agardh, 1824)
*	stones, gravel and coarse sand
*	*Porphyra endiviifolium* (A. et E.S. Gepp) Chamberlain, 1963
*	*Adenocystis utricularis* (Bory) Skottsberg, 1907
Samples from tidepools and the sublittoral fringe:	
suTP	small upper tidepools, i.e. pebbles from small tidepools in the supralittoral or upper eulittoral (less than 0.5 m below uppermost tidemark)
slTP	small lower tidepools, i.e. pebbles from small tidepools in the lower eulittoral (less than 1.5 m above lowest tidemark) and crevices in the sublittoral fringe (down to 0.3 m below lowest tidemark)
llTP	large lower tidepools, i.e. pebbles from large, barren tidepools in the lower eulittoral (less than 1.5 m above lowest tidemark) and flat, open areas in the sublittoral fringe (down to 0.3m below lowest tidemark)
Samples from sublittoral hard bottom environments:	
SR	sublittoral rock
SSG	sublittoral sand and gravel
Am	*Ascoseira mirabilis* Skottsberg, 1907
Bc	*Ballia callitricha* (C. Agardh) Kützing, 1843
Cr	*Curdiea racovitzae* Hariot in De Wildeman, 1900
Dan	*Desmarestia antarctica* Moe et Silva, 1989
Dl	*Delesseria lancifolia* (Hooker fil.) Agardh, 1872
Dma	*Desmarestia menziesii* J. Agardh, 1848 & *D. anceps* Montagne, 1942
Gc	*Georgiella confluens* (Reinsch) Kylin, 1956
Gg	*Geminocarpus geminatus* (Hooker fil. et Harvey) Skottsberg, 1907
GS	*Gigartina skottsbergii* Setchell et Gardner, 1936 & *Sarcothalia papillosa* (Bory) Leister, 1993
Hm	*Himantothallus grandifolius* (Gepp et Gepp) Zinova, 1959
Ho	*Halopteris obovata* (Hooker et Harvey) Sauvageau, 1904
Ic	*Iridaea cordata* (Turner) Bory, 1826
Ka	*Kallymenia antarctica* Hariot, 1907
Pap	*Pantoneura plocamioides* Kylin, 1919
Pc	*Plocamium cartilagineum* (Linnaeus) Dixon, 1967
Phy	*Phyllophora appendiculata* Kylin et Skottsberg, 1919
Pip	*Picconiella plumosa* (Kylin) De Toni, 1936
Sm	*Sarcodia montagneana* (Hooker fil. et Harvey) J. Agardh, 1872
ACI	arborescent colonies of the diatom *Isthmia schmidtii* (Heiden et Kolbe) Simonsen, 1992
Bry1	crustose bryozoan colonies
Bry2	arborescent bryozoan colonies
Samples from sublittoral soft bottom environments:	
M	Mud
Asc	Skin of the ascidia *Molgula gigantea* (Herdman) Kott, 1969
SOL	"Saussage-like" colonies of the diatom *Odontella litigiosa* (Van Heurck) Hoban, 1980

scattered, irregular and rare occurrences. The data given in Fig. 3 thus reflect the potential of the different diatoms to produce larger stocks on different habitats.

It must further be pointed out, that the results of this study do not represent proper diatom communities, as the data may be biassed towards large species. The choosen method of directly observing intact living diatom communities neither permits identification of small species nor an estimation of their abundance to any satisfying degree. Also, in order to complete observations, before the diatom communities were changed too much by artificial conditions, a rapid approach was necessary. This only allowed macroalgae to be treated as specific units, while in reality the arborescent species of HC3 particularly provided a complex of habitats with different diatom species becoming dominant (Thomas & Jiang 1986).

Table 2: Alphabetical list of diatom taxa, which could reliably be identified alive in freshly collected samples at 200-fold magnification under Nomarski differential interference contrast. *1 The genus *Amphiprora* was abandoned and replaced by the genus *Entomoneis* (Patrick & Reimer 1975). The species present in our material, however, have not yet been formally transferred. *2 The genus *Ceratoneis* has been abandoned (Patrick & Reimer 1966). Its species have been transferred to *Nitzschia*, *Gyrosigma* and the new, purely limnic genus *Hannaea*: The present species has not yet been revised, leaving its correct systematic position in question.

Achnanthes sp.
Amphora barrei Manguin, 1960
Amphora bongrainii Peragallo, 1921
Amphora capitellata Frenguelli, 1938
Amphora racovitzae Van Heurck, 1909
Arachnoidiscus ehrenbergii Bailey ex Ehrenberg, 1849
Auricularia compacta (Hustedt) Medlin, 1990
Berkeleya rutilans (Trentepohl) Cleve, 1894
Catacombas camtchatica (Grunow) Williams et Round, 1986
Cocconeis schuettei Van Heurck, 1909
Cocconeis pinnata Gregory, 1855 & *C. costata* Gregory, 1855
Cocconeis sp., small species
Cylindrotheca closterium (Ehrenberg) Reiman et Lewin, 1964
Diploneis sp.
Amphiprora kufferathii Manguin, 1960 *1
Amphiprora gigantea Grunow, 1860 *1
Entopyla australis (Ehrenberg)Ehrenberg, 1848
Fragilaria striatula Lyngbye, 1819
Gomphonema sp.
Grammatophora arcuata Ehrenberg, 1854
Gyrosigma prolongatum (W. Smith) Griffith et Henfrey, 1856
Gyrosigma subsalinum var. *antarcticum* Frenguelli et Orlando, 1958
Hyalosynedra sp.
Isthmia schmidtii (Heiden et Kolbe) Simonsen, 1992
Licmophora antarctica Carlson, 1913 & L. belgica Peragallo, 1921
Licmophora gracilis (Ehrenberg) Grunow, 1867
Manguinea fusiformis (Manguin) Paddock, 1990
Melosira charcotii Peragallo, 1921
Melosira moniliformis (Müller) C.A. Agardh, 1824
Melosira nummuloides C.A. Agardh, 1824
Navicula directa (W. Smith) Ralfs, 1861
Navicula lacunosa (Heiden et Kolbe)Simonsen, 1992
Navicula sp., >30µm
Navicula sp., <30µm
Nitzschia adeliana Manguin ,1960
Nitzschia hybrida Grunow, 1880
Nitzschia medioconstricta Hustedt, 1958
Nitzschia stellata Manguin 1960,
Odontella litigiosa (Van Heurck) Hoban, 1980
Paralia sol (Ehrenberg) Crawford, 1979
Parlibellus delognei (VanHeurck) Cox, 1988
Parlibellus schuettei (Van Heurck) Cox, 1988
Pinnularia quadratarea (W. Schmidt) Cleve, 1895
Pleurosigma directum Grunow in Van Heurck, 1880
Pseudogomphonema kamtchaticum (Grunow) Medlin, 1990
Rhoicosphenia cf. curvata (Kützing) Grunow, 1860
Tabularia investiens (W. Smith) Williams et Round, 1986
Ceratoneis australis M.Peragallo, 1921 *2
Thalassiosira australis Peragallo, 1921
Trachyneis aspera (Ehrenberg) Cleve ,1894
Triceratium arcticum Brightwell, 1853

RESULTS

No diatoms were found on rock or sand exposed to the air during low tide, or on the algae *Porphyra endiviifolium* and *Adenocystis utricularis*, which also dry out at low tide. These substrata are excluded from further consideration. The cluster analysis of the other substrata yielded three large habitat clusters (HC: Fig. 1). HC1 represents all remaining habitats of the intertidal and the sublittoral fringe. HC2 includes all frondose macroalgae, but also coarse sediment samples and the arborescent colonies of *Isthmia schmidtii* (ACI). HC 3 includes almost all bushy macroalgae, bryozoans and samples from rocks and stones. Four categories remained independent within the 50% dissimilarity limit: the small branched macroalga *Geminocarpus geminatus* (Gg), the "sausage-like" colonies of *Odontella litigiosa* (SOL), the samples from mud (M), and the samples from ascidian skins (Asc).

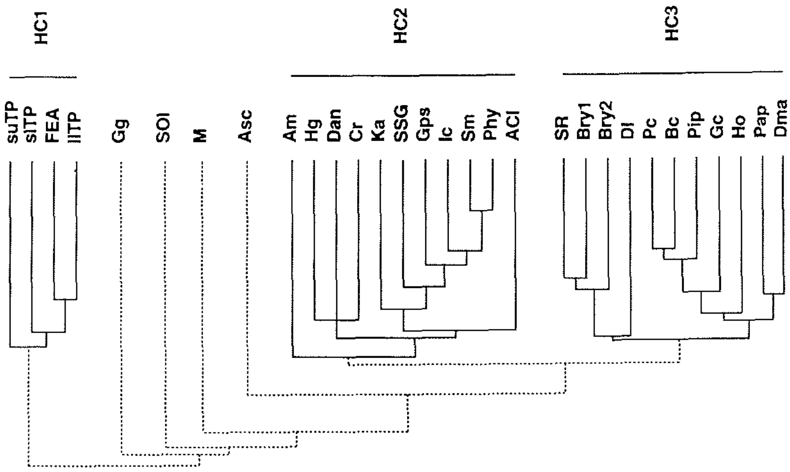

Fig. 1: Dendrogram (Bray-Curtis-Index, UPGMA, K = 0.88) for diatom assemblages on different types of substrata: suTP = stones from small tidepools of the upper eulittoral and supralittoral, slTP = small tidepools of the lower eulittoral, FEA = filamentous eulittoral algae, lITP = stones from large tidepools of the lower littoral, Gg = *Geminocarpus geminatus*, SOL = sausage-like colonies of *Odontella litigiosa*, M = mud, Asc = ascidian skin, Am = *Ascoseira mirabilis*, Hg = *Himantothallus grandifolius*, Dan = *Desmarestia antarctica*, Cr = *Curdiaea racovitzae*, Ka = *Kallymenia antarctica*, SSG = sublittoral sand and gravel, Gps = *Gigartina papillosa* & *G.skottsbergii*, Ic = *Iridea cordata*, Sm = *Sarcodia montagneana*, Phy = *Phyllophora appendiculata*, ACl = arborescent colonies of *Isthmia enervis*, SR = sublittoral rock, Bry1 = crustose bryozoan colonies, Bry 2 = arborescent bryozoan colonies, Dl = *Delesseria lancifolia*, Pc = *Plocamium cartilagineum*, Bc = *Ballia callitricha*, Pip = *Picconiella plumosa*, Gc = *Georgiella confluens*, Ho = *Halopteris obovata*, Pap = *Pantoneura plocamioides*, Dma = *Desmarestia anceps* & *Desmarestia menziesii*.

The cluster analysis of diatom distribution patterns resulted in eleven small clusters (DDC: Fig. 2) and eleven independent categories on a dissimilarity level of 50%. If a dissimilarity level of 75% is considered, however, five large cluster groups are formed, leaving out only two species. These groups coincide with the arrangement of habitat categories (Fig. 3): The first group, including DDC1 and *Parlibellus delognei*, represents those diatoms, which almost exclusively appear in the intertidal (Figs. 3,4). The second group includes all widely distributed species. Of these, the distribution of the species of DDC 2 centers on three-dimensional structures (HC3). They are also important as epiphytes in the intertidal, even in the uppermost small tidepools and on filamentous algae (Fig. 4), which are otherwise only colonized by species of DDC1. The species of DDC3 are ubiquitious in the sublittoral, but only rarely occur in the lower parts of the intertidal (Figs. 3, 4). The diatoms show a similar distribution in DDC4, but abundances are generally low. The rest of group 2, including DDC5 and DDC6 shows a tendency to avoid open, unprotected surfaces (HC2). It should be noted, that species of group 2 may produce bloom-like prolifera

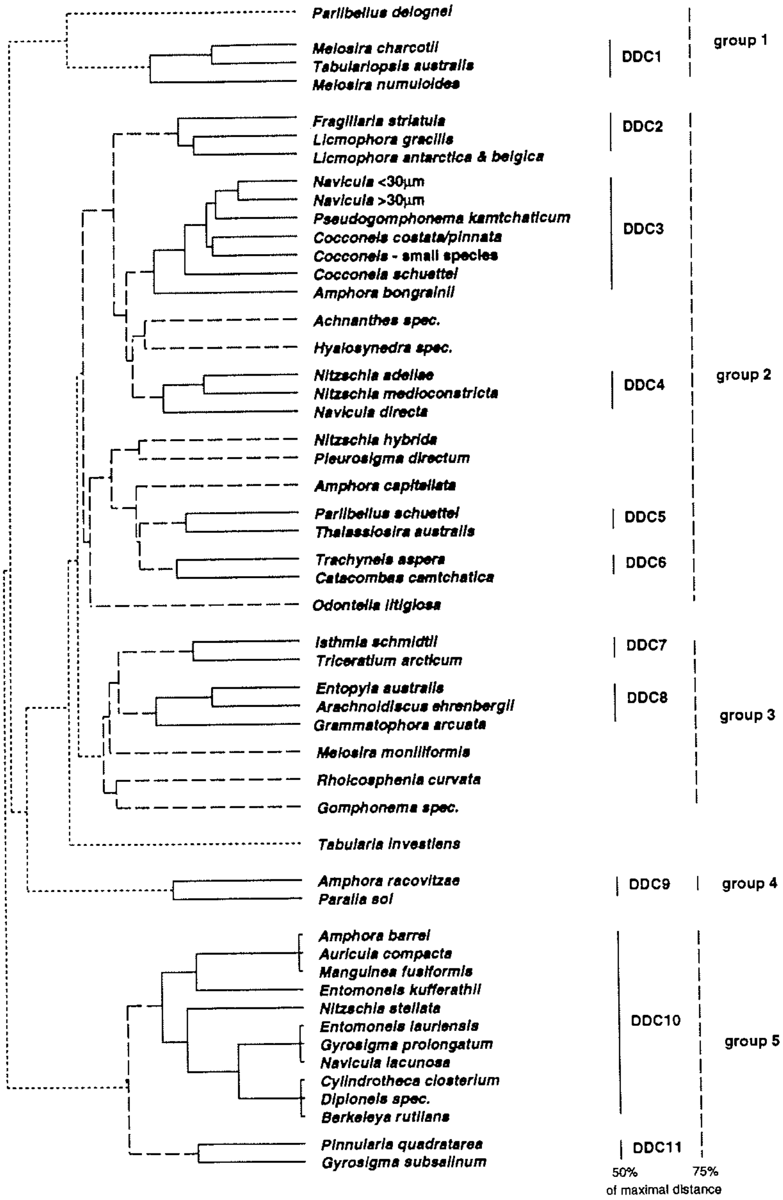

Fig 2: Dendrogram (Bray-Curtis-Index, UPGMA, K = 0.91) for diatom distribution patterns. Groupings are indicated according to the 50% dissimilarity level (DDC1-11) and to the 75% dissimilarity level (groups 1-5).

tions: *Achnanthes sp.* and *Fragilaria striatula* form benthic spring blooms on stone and rock substrata. *Odontella litigiosa*, which has a wide but scattered distribution, may form long colonial chains, which eventually result in interwoven, "sausage-like" masses up to a length of 30 cm and a diameter of about 10 cm. The tube-dwelling *Parlibellus schuettei* is frequently codominant with *Melosira numuloides* in small ti

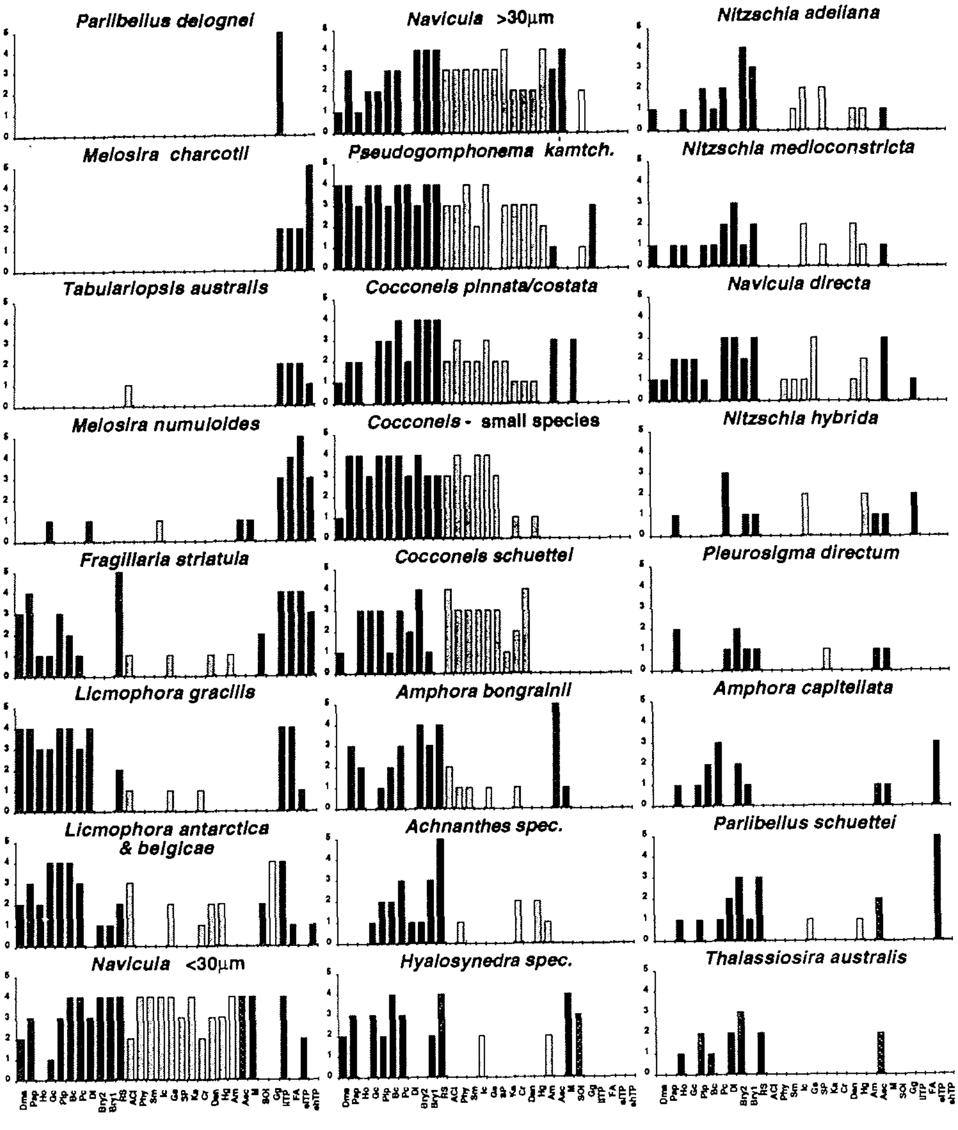

Fig. 3a: Estimated maximum abundance of diatom species in live samples from different benthic habitats. The order of species and substrata follows the arrangement in Fig. 1 and Fig. 2, respectively. Abbreviations for substrata are identical with Fig. 1. Further explanations in Fig. 3b.

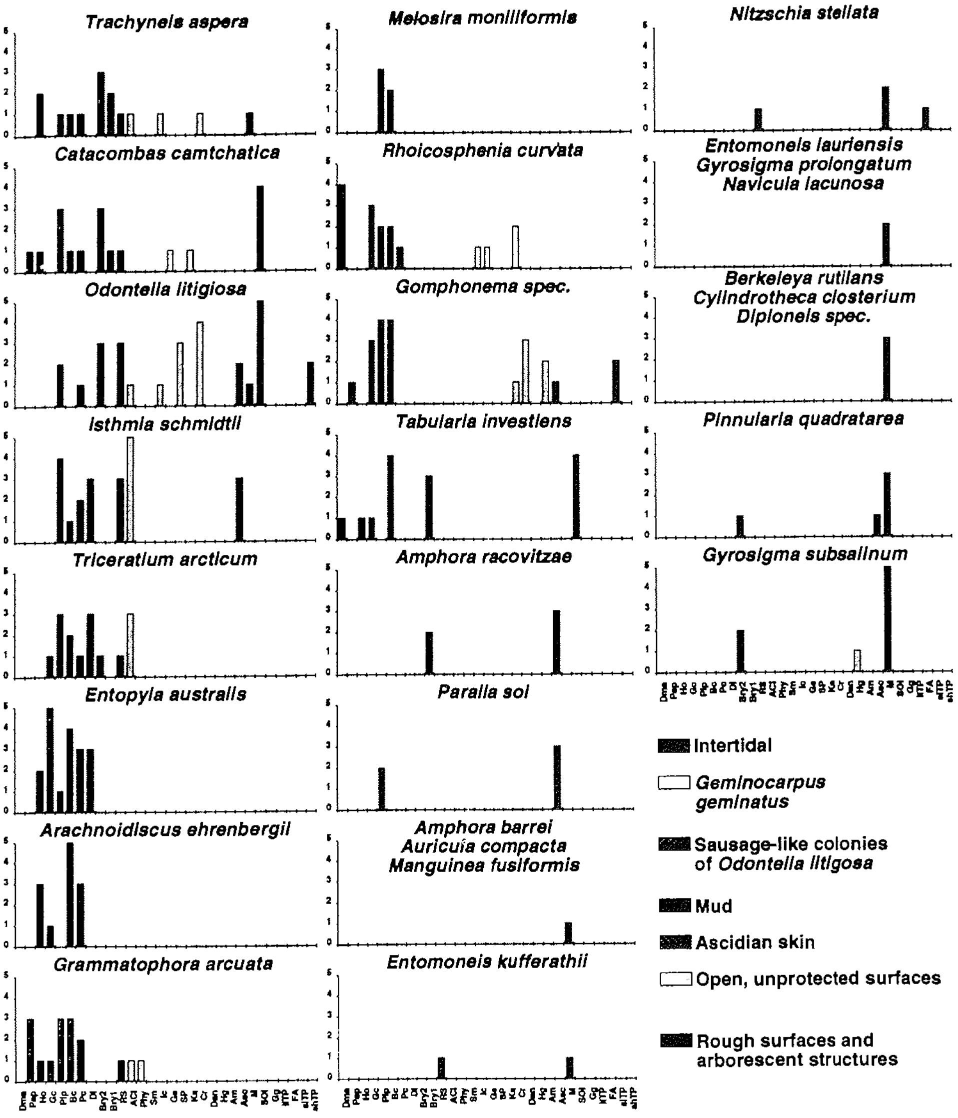

Fig. 3b: Estimated maximum abundance of diatom species in live samples from different benthic habitats. The order of species and substrata follows the arrangement in Fig. 1 and Fig. 2, respectively. Abbreviations for substrata are identical with Fig. 1.

depools of the lower sublittoral and in the sublittoral fringe. *Amphora bongrainii* regularly dominates on ascidian skins.

The third group consists of 2 small clusters and 3 additional species, all of which share their affinity to HC3. Most restricted are the species of DDC 8 and *Melosira moniliformis*, which were exclusively found on small bushy rhodophytes. *Isthmia schmidtii* may also proliferate on rough stone surfaces and ascidian skins. This species may build arborescent colonies up to a height of 5 cm, which provide the prefered habitat of *Triceratium arcticum*. The more widely distributed *Rhoicosphenia curvata* is the only species of this group which grows on the large bushy phaeophytes *Desmarestia anceps* and *D. menziesii*.

The fourth group is identical with DDC9 and comprises *Amphora racovitzae* and *Paralia sol*. Both species were abundant on ascidian skins, but otherwise rare.The fifth group is comprised of DDC10 and 11, which contain species almost exclusively confined to fine sediments. They exhibit a tendency to occur only at greater depth (Fig. 4).

DISCUSSION

In the Antarctic, we still are far from understanding, why a species becomes dominant under certain conditions. For example, the large bushy algae *Desmarestia anceps* and *D. menziesii* (HC3: Dma) are primarily colonized on their small, outer branchlets: While exposed parts and tips of the branchlets are colonized by *Licmophora spec.*, the axils are almost exclusively occupied by *Rhoicosphenia spec.*. The flat stipes in the interior of *Desmarestia* are only poorly colonized by *Cocconeis spec.*, possibly because of a self-shading effect of these massive plants.

This differentiation may also explain the position of *Geminocarpus geminatus* (Fig. 1). Growing almost exclusively as an epiphyte on *Desmarestia*, its diatom assemblage is principally identical with what is found on the branchlet tips of *Desmarestia*: However, as the rest of the diatom spectrum of *Desmarestia* is lacking in *Geminocarpus*, it is kept apart from its host plant (and from other bushy algae) in the cluster analysis. It may be noted, that Thomas & Jiang (1986) reported a high abundance of *Nitzschia lecointei* on *Geminocarpus*, which is usually reported from sea ice (e. g. Garrison 1991).

The other small bushy algae carry a similar basic diatom assemblage like *Desmarestia*. However, frequently basal parts of *Plocamium cartilagineum*, *Halopteris obovata*, *Picconiella plumosa* and *Georgiella confluens* additionally carry colonies of *Entopyla australis* and, if this diatom is present, sometimes also *Arachnoidiscus ehrenbergii*. In *Ballia callitricha*, these latter diatom species even grow on the tips of branchlets and become so prominent, that the general character of the diatom assemblage appears to be altered. This may possibly reflect a succession from an initial widespread *Licmophora/Cocconeis* stage to the final appearance of *Arachnoidiscus*. The latter would then indicate the most stable and persistent microhabitats.

Similarly, *Isthmia schmidtii* and its close associate *Triceratium arcticum* seem to appear later in the supposed *Licmophora/Cocconeis* stage. Although these species belong to the group of species (group 3: Fig. 2), which characterize the assemblages of HC3, they formed an assemblage of their own, clustered in HC2 (ACI: Fig. 1). It occurred in four isolated places: on an ascidian, on single individuals of *Plocamium cartilagineum*, *Delesseria lancifolia*, and on a bare, exposed rock. Here, the apparently highly competitive *Isthmia schmidtii* forms dense arborescent colonies of about 5 cm height, on which only a number of ubiquitious diatoms (group 2: Fig. 3) grow epiphytically, while the only characteristic species from group 3, *Triceratium arcticum*, densely fills the interstices.

The rest of HC2 appears to be negatively defined, because no characteristic species is present. Occasionally, a denser growth of predominant *Cocconeis* species is observed, coincident with findings of Thomas & Jiang (1986). Usually, however, these and other ubiquitious or widely scattered diatoms of group 2 are present in low abundances only. Thus, in contrast to HC3, which represents three-dimensional structures (arborescent macroalgae and Bry2) or surfaces sufficiently rough to provide sheltered microhabitats (RS and Bry1), HC2 may be interpreted as either smooth and unprotected (all macroalgae of HC2) or too mobile (SSG) habitats, permitting only ephemeral diatom growth (except the special case ACI).

Ascidian tunicae were kept as an independent category (Asc: Fig. 1). This was surprising, as the tunicae are just smooth surfaces colonized by ubiquitious species of DDC 3, with *Amphora bongrainii* being highly dominant. However, the occurence of *Amphora racovitzae* and *Paralia sol* of DDC 9 gave a special quality to this habitat.

The mud also remained an independent category (M: Fig. 1). In contrast with Asc, however, this habitat is well characterized by a number of species (DDC 9 and 10), which occur here exclusively or only rarely somewhere else (Fig. 3), including some species, which are well known as ice algae (*Amphora barrei*, *Auricula compacta*; *Amphiprora kjellmanii*, *Nitzschia stellata*: e. g. Whitaker 1977; Grossi & Sullivan 1985; Garrison *et al.* 1987; Klöser 1990). Of these, *Amphora barrei* was reported to be dominant in high Antarctic sediments (Rivkin & DeLaca 1990), but - like the other ice algae - is only present in low numbers in our material. In greater depth (Fig. 4) , where resuspension events may be negligible, mats of highly dominant *Gyrosigma subsalina* usually develop. These mats are repeatedly buried by sediments. In this case, *Navicula directa*, *Cylindrotheca closterium* and *Pinnularia quadratarea* take over for some days, before the *Gyrosigma* mats are re-established. Although *Gyrosigma* in general is an epipelic genus (Round *et al.* 1990), it has not yet been reported to play an important role in the Antarctic. Instead, *Odontella litigiosa*, *Catacombas camtchatica*, *Cylindrotheca closterium*, *Trachyneis aspera*, *Cocconeis spec.*, *Fragilaria spec.* were reported from sediment (Palmisano *et al.* 1985; Gilbert 1991a, b; Ahn *et al.* 1994), and *Odontella litigiosa*, *Odontella weisflogi*, *Actinocyclus actinochilus*, *Paralia sol*, *Cocconeis spec.*, *Thalassiosira australis*, *Pinnularia spec.*, *Fragilaria striatula* and *Navicula spec.* from unspecified "sublittoral bottom" (Frenguelli & Orlando 1958; Krebs 1983). This might reflect more disturbed conditions generally.

Another independent category (SOl: Fig. 4) were the *Odontella litigiosa* "sausages" (Fig 3e), which were found freely drifting over muddy substrata. Therefore, these "sausages" may develop as a result of a benthic bloom, although in this study *Odontella litigiosa* never was abundant on the mud itself (Fig. 3). These drifting masses were frequently entangled in ascidian clumps and other projections. Similarly, webs of *Odontella litigiosa* covered stands of *Desmarestia spec.* at Signy Island (Heywood & Whitaker 1984).

All intertidal habitats were united in one cluster (HC1: Fig. 1) being most dissimilar to all other habitats, although diatoms of DDC2 and some other species build some links to HC3. Species of *Licmophora* and *Fragilaria striatula* have been reported as important components of intertidal assemblages before (Frenguelli & Orlando 1958; Délepine & Hureau 1963; Hedgpeth 1969; Krebs1983; Ligowski 1993; Ahn *et al.* 1994). Of the species of DDC1, which in this material are highly characteristic and dominant in the intertidal, few records exist. The only other records of tidepools dominated by *Melosira* are from Délepine & Hureau (1963) and Heywood & Whitaker (1984). Instead, *Achnanthes* species were frequently reported to dominate (Peragallo 1921; Hedgpeth 1969; Krebs 1983;), which in this study were only found in the sublittoral (Fig. 3). Although all intertidal habitats share the same assemblage of species, the abundances differ: In large shallow tidepools of the lower littoral (lITP) *Fragillaria striatula*, *Pseudogomphonema camtchatica* and *Melosira* species may be abundant at times of benthic spring blooms. Usually, however, the diatom vegetation is poor, possibly due to the seasonal immigration of grazing limpets. A notable exception is the tube-dwelling, macroalgae-like *Parlibellus delognei*. Small tidepools of the lower littoral and small crevices of the sublittoral fringe (slTP) usually contain strands of *Melosira numuloides* and tubes of *Parlibellus rhombica*. In small tidepools of the upper littoral (suTP), *Melosira charcotii* builds up a dense, almost monospecific vegetation. Probably, other diatoms are hardly able to tolerate the strong variations of salinity and temperature in this habitat. The filamentous eulittoral algae (FEA) represent the only substratum falling dry during low tide and suitable as a habitate for an epiphytic diatom vegetation. It is probably protected from drying out, because the algal filaments provide a dense humid cover during low tide.

Conclusions

A number of assemblages could be distinguished relating to different types of habitats. However, the principal separation did not follow the classical scheme of epilithic, epiphytic, epipsammic, epipelic and epizoic communities, but rather seemed to reflect structural properties of the habitats and exposure to disturbance. Most habitats are well characterized by typical assemblages of diatoms: the intertidal, large clumps of *Odontella litigiosa*, mud, and three-dimensional structures like bushy macroalgae, bryozoans and rough stone surfaces (HC3). Another well-characterized group, albeit negatively, includes all substrata difficult for diatom colonization (HC2). The positon of *Geminocarpus* and ascidian tunicae remains unsatisfactory at present. Distribution patterns in group 1 coincide with intertidal habitats, group 3 with HC3, group 5 with muddy habitats. Group 4, characteristic for ascidian tunicae, is doubtful, and group 2 represents more or less indifferent species. The only partial coincidence with information from earlier authors, and the high level of dissimilarity in the formation of the groups of distributional patterns readily pinpoints the need for more detailed studies.

References

AHN I.Y., CHUNG H., KANG J.S. & KANG S.H. 1994. Preliminary studies on the ecology of neritic marine diatoms in Maxwell Bay, King George Island, Antarctica. *The Korean Journal of Phycology* 9(1): 37-45.

BAKUS G.J. 1990. *Quantitative Ecology and Marine Biology*. A.A. Balkema, Rotterdam: 157pp

BERKMAN P.A., MARKS D.S. & SHREVE G.P. 1986. Winter sediment resuspension in McMurdo Sound, Antarctica, and its ecological implications. *Polar Biology* 6: 1-3.

DELÉPINE R. & HUREAU J.C. 1963. La végétation marine de l'archipel de Pointe Géologie (Terre Adélie). *Bulletin del Musée de Histoire Naturelle* 35 (1): 108-119.

FRENGUELLI J. & ORLANDO H.A. 1958. Diatomeas y silicoflagellados del Sector Antárctico sudamericano. *Contribuciones del Instituto Antártico Argentino* 5: 15-191.

GARRISON D.L. 1991. Antarctic Sea Ice Biota. American Zoologist 31: 17-33

GARRISON D.L., BUCK K.R. & FRYXELL G.A. 1987. Algal assemblages in Antarctic pack ice and in ice-edge plankton. *Journal of Phycology* 23: 564-572

GILBERT N.S. 1991a. Primary production by benthic microalgae in nearshore marine sediments of Signy Islands, Antarctica. *Polar Biology* 11: 339-346.

GILBERT N.S. 1991b. Microphytobenthic seasonality in near-shore marine sediments at Signy Island, South Orkney Islands, Antarctica. *Estuarine, Coastal and Shelf Science* 33: 89-104.

GROSSI S.M. & SULLIVAN C.W. 1985. Sea ice microbial communities. V. The vertical zonation of diatoms in an Antarctic fast ice community. *Journal of Phycology* 21: 401-409.

HAPTER R., WOZNIAK B. & DOBROWOLSKI K. 1983. Primary production in Ezcurra Inlet during the Antarctic summer of 1977/78. *Oceanologia* 15: 175-184

HEDGPETH J.W. 1969. Preliminary observations of life between tidemarks at Palmer Station, 64° 45' S, 64° 05' W. *Antarctic Journal of the United States* 4(4): 106-107.

HEYWOOD R.B. & WHITAKER T.M. 1984. The Antarctic marine flora. In: *Antarctic Ecology vol 2* (Ed. by R.M. Laws), pp. 373-419. Academic Press, London

KLÖSER H. 1990. Verteilung von Mikroplankton-Organismen nordwestlich der Antarktischen Halbinsel unter dem Einfluß sich ändernder Umweltbedingungen im Herbst. *Berichte zur Polarforschung* 77: 255 pp

KLÖSER H., MERCURI G., LATURNUS F., QUARTINO M.L., WIENCKE C. 1994a. On the competitive balance of macroalgae in Potter Cove (King George Island, South Shetlands). *Polar Biology* 14: 11-16.

KLÖSER H., FERREYRA G., SCHLOSS I., MERCURI G., LATURNUS F., CURTOSI A. 1994b. Hydrography of Potter Cove, a small fjord-like inlet on King George Island (South Shetlands). *Estuarine, Coastal and Shelf Science* 38: 523-537

KREBS W.N. 1983. Ecology of neritic marine diatoms, Arthur Harbor, Antarctica. *Micropaleontology* 29(3): 267-297

PALMISANO A.C., SOOHOO J.B., WHITE D.C., SMITH G.A., STANTON G.R. & BURCKLE L.H. 1985. Shade adapted benthic diatoms beneath Antarctic sea ice. *Journal of Phycology* 21: 664-667.

PERAGALLO M. 1921. Diatomées d´eau douce et diatomées d´eau salée. *Deuxième Expédition Antarctique Française 1908-1910. Botanique*: 98 pp.

PLATT H.M. 1979. Ecology of King Edward Cove, South Georgia: Macro-benthos and the benthic environment. *British Antarctic Survey Bulletin* 49: 231-238.

RIVKIN R.B. & DELACA T.E. 1990. Trophic dynamics in antarctic benthic communities. I. In situ ingestion of microalgae by Foraminifera and metazoan meiofauna. *Marine Ecology Progress Series* 64: 129-136.

WHITAKER T.M. 1977. Sea ice habitats of Signy Island (South Orkneys) and their primary productivity. In: *Adaptations within Antarctic ecosystems* (Ed. by G.A. Llano), pp. 75-82. Gulf Publishing Company, Houston.

A first record of the soft bottom infauna community of Potter Cove

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Benthic infauna communities in Antarctic littoral and sublittoral habitats are influenced by ice action and discharge of sediment loaded meltwater. This is definitely valid for Potter Cove, where meltwater run-off from land carries up to 60 kg of sedimentary material per liter during the summer months (Varela, this volume). This is indicated to affect species abundance and community structure in general resulting in different communities as compared to clearer waters like the adjacent Maxwell Bay (Ahn & Kang 1991), Admirality Bay (Jazdzewski et al. 1986, Arnaud et al. 1986) or McMurdo Sound (Dayton & Oliver 1977).
The epifaunal assemblages of Potter Cove have hitherto been described on the basis of photo transects (Sahade et al. this volume). The present study aims at describing distribution and abundance of smaller and infaunal elements of the soft bottom areas of the inner cove.

Along four transect lines a total of 23 stations was sampled during February and March 1997. At all stations the sediment consisted of fine mud. The first transect streched across the cove entrance, the second from the Dallmann Laboratory aquaria towards the glacier, the third in front of Casa Bomba and the fourth in front of the lighthouse across the bay (fig 1.) At each station 3 replicate samples were taken with a 16,5•16,5 cm van-Veen grab. The samples were washed over an 1 mm^2 mesh and the total of infaunal individuals was stored in 70% alcohol. Deep burrowing species like the bivalve *Laternula elliptica* or big ascidians were rejected, because the sampling gear was not appropriate to adequately evaluate their number or biomass.
Determinations were done to orden or family level, which is an appropriate method and does not alter the results in comparison to time consuming species identification methods (Heip et al. 1988, Somerfield and Clarke, 1995).

Table 1: List of stations according to transsects, water depths and infauna densities (individuals/m^2)

	I.1 7m	I.2 15m	I.3 33m	I.4 31m	I.5 36m	II.1 5,3m	II.2 15m	II.3 20m	II.4 28m	II.5 33m	II.6 38m	II.7 36m	III.1 8m	III.2 32m	III.3 35m	III.4 39m	III.5 32m	IV.1 5m	IV.2 20m	IV.3 25m	IV.4 24m	IV.5 32m	IV.6 20m
Stolonifera	12																						
Pennatulidae					61		294	2583	49	49	331	37	18				12						
Nemertini		49	49	12											37								
Cyclostomat.																							
Bryozoa sp.					6										6			6					
Priapulida	2473		12			12	25		12	12													
Cephalaspidea										147													
Neobuccinum				37														37					
Gastropoda sp	25		49			12				61	25				25	37	12						25
Yoldia eightsii		269	135	12	12	796	159					61	753		49		318	220	122			12	61
Bivalvia sp	6232	882	796	98	74	25	465	1175	208	86	220	98	37	1040	441	184	661	61	698	122	110	61	784
Spionidae	808																						
Orbiniidae	1199																						
Maldanidae										25		49	37	25	122								
Terebellidae				12	49				61			12		25	12		49			12			
Polynoidae				12					25	12		12		12	37	37	12	12					
Nephtiidae						12		12,2		12	12		37	12		37							
Opheliidae						37																	
Cirratulidae										416	196	122	661		12		74	12			49		
Polychaeta sp	86	4162	5754	355	220	882	1432	2118	502	269	294	61	184	49	416	110	306	25	74		37		12
Amphipoda	9011	2546	1187	25	37	306		61	110	25	196	233	92	37	306	74	98	147	294	135	465	122	343
Cumacea	367	465	294		25	257	1799	539	147	245	25	135	2020	441	184	257	612	1995	1603	637	1665	159	551
Serolidae	12																						
Isopoda sp		918	12												86		12						
Tanaidacea		208	49												37								12
Mysidacea	12																						
Scleroconcha		257	25																				
Ophiuroidea					12																		
M. musculus								37			25	12											
Total	2023	9758	8362	563	495	2338	4175	6525	1114	1359	1322	832	3838	1640	1769	734	2167	2516	2791	906	2326	355	1787

The soft bottoms of the inner Potter Cove are dominated by peracarid crustaceans (41%), small bivalves (22%), polychaetes (27%), priapulids (4%) and coelenterates (5%) (Fig.2; Table 1). The mean density is 4.202 ind•m^{-2}, showing a decrease from 7.233 ind•m^{-2} in 10m depth to 1.779 ind•m^{-2} in 50m depth (tab.1). Below 20m individual numbers of all taxa decrease sharply with the exception of the polychaetes. A replacement of bivalves by polychaetes with increasing water depth seems to display a general trend and has previously been observed by Hardy (1972, Signy Island), Gallardo et al. (1977, Greenwich Island) and Jazdzewski et al. (1986, King George Island).

The species in the upper zone are usually mobile like amphipods and some polychaetes, perennial, fast growing species like pennatularians or small bivalves like *Yoldia eightsii.* This zone experiences strong ice impact during the summer months (Kühne 1997) which conflicts with the settlement of most big sessile species with the exception the deep burrowing bivalve *Laternula elliptica* (Kowalke 1997). On the other hand some ice growlers may disturb epi- as infaunal communities down to 15m and thus offer a rich food source of decaying animals for various scavengers like amphipods, typical for Antarctic soft bottom communities (Dell 1972, Arnaud 1974, Jazdzewski et al. 1986). Small bivalves are probably not as much affected by ice drift due to their relatively hard shells and their ability to rebury quickly (pers. observation).

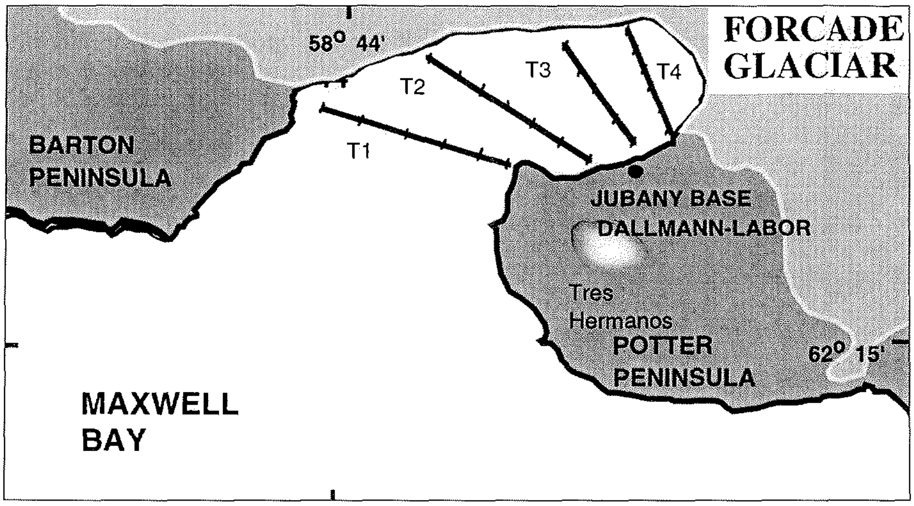

Fig.1: Potter Cove with transects and sampling stations

The largely undisturbed zone below 20m is dominated by solitary ascidians (Sahade et al., this volume) which seem to outcompete other suspension feeding animals (tab.1). Moreover, peracarid crustaceans, mainly amphipods and cumaceans, occur in reduced densities below 20m.

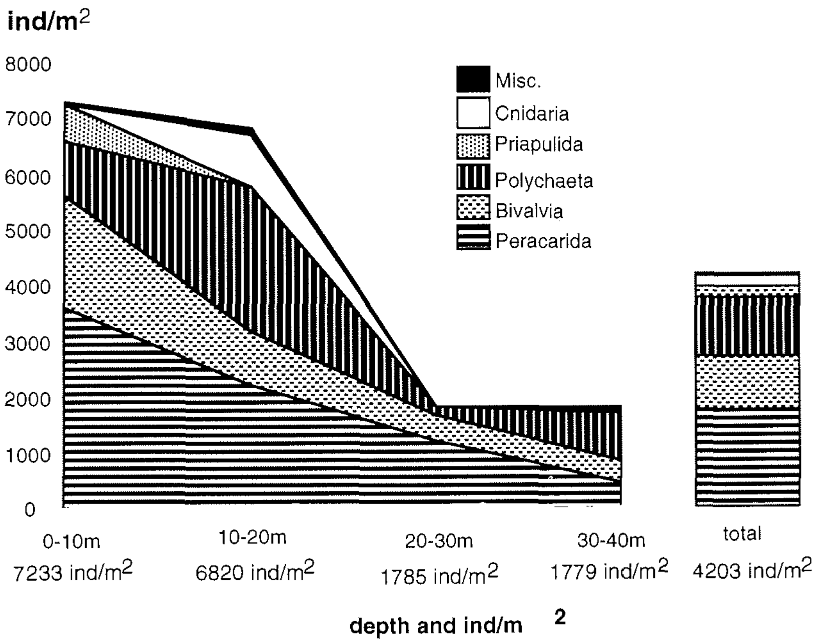

Fig. 2: The most abundant taxa (ind m^{-2}) in the Potter Cove, for 4 different dephts and for the Potter Cove as a whole, stations from all transects pooled, the mean was calculated taking the percentage cover of each depth into account; miscellaneous category contains echinoderms, gastropods, nemerteans and bryozoans

The mean animal density of 4.200 ind•m^{-2} is much higher than the findings of Ahn and Kang (1991) from the adjacent Marian Cove. These authors found a mean of 190 ind•m^{-2} using the same mesh size of 1 mm^2. Jazdzewski et al. (1986), using a 0,5 mm2 mesh found ca 12.000 ind•m^{-2} in 15m and ca. 5.000 ind•m^{-2} in 30m water depth in the Ezcurra Inlet, a small, sediment charged inlet of Admirality Bay. Dayton and Oliver (1997) counted up to 155.000 ind•m^{-2} in a eutrophic part of McMurdo Sound with tanaidaceans, isopods and polychaetes forming the most abundant taxa.

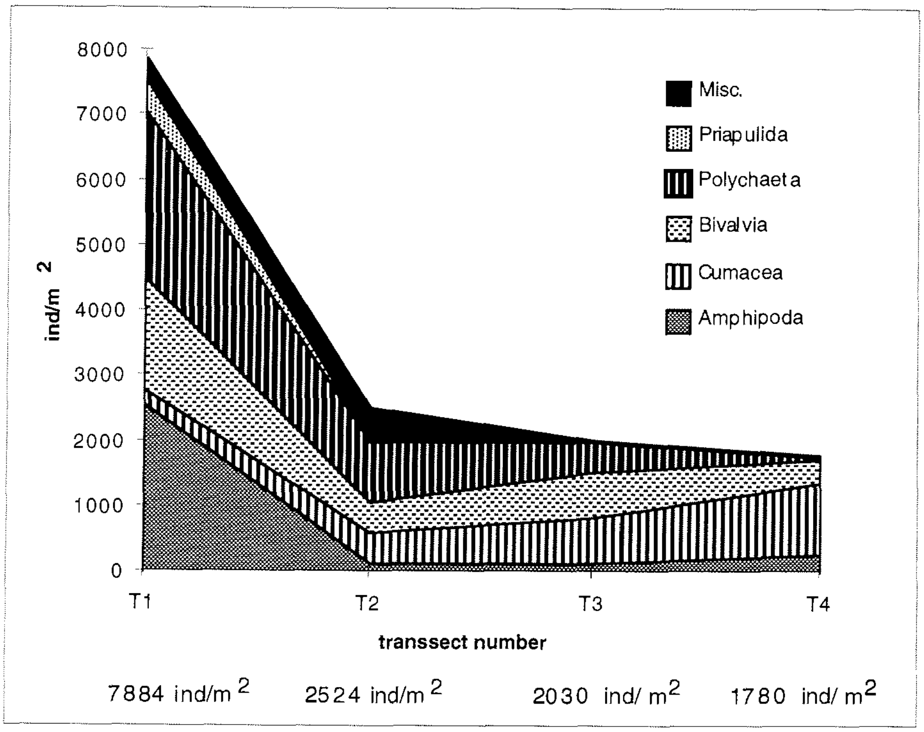

Fig. 3: The most abundant taxa (individuals•m $^{-2}$) in the Potter Cove for the 4 transect lines, stations from all depths pooled; miscellaneous category contains echinoderms, isopodes, tanaidaceans, mysidaceans, gastropods, nemerteans and bryozoans

Along the four transect lines the total number of individuals changes (tab. 1, fig. 3). The first transect , dominated by amphipoda and polychaeta, has nearly four times as much individuals as the other three inside the cove. In the fourth transect, far inside the cove, the cumacea comprise 60% of all individuals and polychaetes are insignificant (tab.1, fig. 3). This may relate to the meltwater inflow carrying sediment run-off from the biggest meltwater discharge located at the far end of Potter Cove. Cumaceans are deposit feeders, which consume bacteria and sedimentary organic material. All other taxa, aside from the cumaceans, exhibit diminishing individual numbers from the entrance towards the inner end of the cove. In case of the bivalves this can be attributed to clogging of the filtering apparatus at high concentrations of dispersed sediment in the waters of the inner cove. Likewise, polychaetes appeared sensitive to high sediment concentrations and were, therefore, also more abundant in the entrance of the cove, where the water was clearer. The distribution of secondary feeders like amphipods, isopods or ophiuroids was determined by the availability of potential prey organisms. Obviously, cumaceans can cope with high loading of sedimentary material and, consequently, are very abundant at most transect 4 stations in the inner cove.

Conclusion: This first record of the soft bottom in- and epifauna of Potter Cove depicts a similar pattern as has been described for other Antarctic habitats with intermediate individuals densities. The finding that cumaceans occur at higher numbers as compared to other studies was attributed to the relatively high sediment discharge into the inner Cove. Unfortunately no sediment parameters like oxygen or organic content are available yet, which could be related to the abundances of the animals.

We suggest the sampling to be repeated during future campaigns and extended with regard to biomass analyses which may depict a somewhat different pattern, if big species like *L. elliptica*, ascidians or sponges are to be included.

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References

Ahn, I.Y. and Kang, Y.C. 1991. Preliminary study on the macrobenthic community of Maxwell Bay, South Shetland Islands, Antarctica. Kor. J Pol. Res. 2 (2), pp 61-71

Arnaud, P.M. 1974. Contribution à la bionomie marine benthique des regions antarctiques et subantartiques. Tethys 6, pp 465-656

Arnaud, P.M., Jazdzewski, K., Presler, P. and Sicinski, J. 1986. Preliminary survey of benthic invertebrates collected by Polish Antarctic expeditions in the Admirality Bay, King George Island, South Shetland Islands. Pol. Polar Res. 7, pp 7-24

Dayton, P.K. and OliverJ.S. 1977. Antarctic soft bottom benthos in oligotrophic and eutrophic environments. Science 197, pp 55-58

Dell, R.K. 1972. Antarctic benthos. Adv. mar. Biol. 10, pp 1-216

Hardy, P. 1972. Biomass estimates for some shallow water infaunal communities at Signy Island, South Orkney Islands. Br. Ant. Survey Bull. 30, pp 93-106

Gallardo, V.A., Castillo, J.G., Retamal, M. A., Yáñez, A., Moyano, H.J. and Hermosilla, J.G. 1977. Quantitative Studies on the soft-bottom macrobenthic animal communities of shallow Antarctic bays.- in: Llano (Hrsg.), Adaptation within Antarctic ecosystems, Proc. 3. SCAR on Ant. Biol., pp 361-387

Heip, C., Warwick, R.M., Carr, M.R., Herman, P.M., Huys, R., Smol, N. and Van Holsbeke, K. 1988. Analysis odf community attributes of the benthic meiofauna of Frierfjord/Langsundfjord. Mar. Ecol. Prog. Ser. 46, pp 171-180

Jazdzewski, K., Jurasz, W., Kittel, W., Presler, E., Presler, P. and Sicinski, J. 1986. Abundance and biomass estimates of the benthic fauna in Admirality bay, King George Island, South Shetland Islands. Pol. Biol. 6, pp 5-16

Kowalke, J. 1997. Energieumsätze benthischer Filtrierer der Potter Cove, King George Island, Antarktis. Dissertation Univ Bremen, 138 pp

Kühne, S. 1997. Solitäre Ascidien in der Potter Cove (King George Island, Antarktis. Ihre ökologische Bedeutung und Populationsdynamik. Dissertation Universität Bremen, 153 pp

Somerfield, P.J. and Clarke, K.R. 1995. Taxonomic levels, in marine community studies, revisited. Mar. Ecol. Prog. Ser. 127, pp 113-119

SOME ASPECTS ON ANTARCTIC ASCIDIANS (TUNICATA, ASCIDIACEA) OF POTTER COVE, KING GEORGE ISLAND.

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INTRODUCTION

The Antarctic ascidians have been described by various authors (see references in Monniot & Monniot 1983). These descriptions were based on samples collected from ships and give no reference to the habitat of the different species. Although an important proportion of the Antarctic bottom is covered by ascidians, the sublittoral zone of this continent is unfavourable to the settlement of sessile animals owing to ice impact, icebergs and anchor-ice (Hedgpeth, 1969; Dayton *et al.* 1970). The type of substrate is one of the most restrictive conditions to the settlement and distribution of ascidians (Monniot, 1965; Turon, 1988). Since the larval period is very short (Svane & Young, 1989), the scarcity of suitable areas for their settlement is a limiting factor to the species dispersion (Monniot, 1965).

This paper reports the ascidian species of Potter Cove and describes their distribution on different substrate types.

MATERIALS AND METHODS

Type locality: Potter Cove, King George Island, South Shetlands , Antarctica (62° 14' S, 58° 40' W), where the Argentinian station Jubany and the Argentinian-German laboratory Dallmann are situated, is a tributary inlet close to the entrance of Maxwell Bay, one of the two big fjords of King George Island.

The Cove is divided into a mouth and an inner part. The mouth has an area of about 3 km^2 and is bordered by steep slopes down to 100 m to the North while it opens onto a broad intertidal platform to the Southwest. Hard bottoms and macroalgae dominate this area (Klöser *et al.* 1994). The inner cove has an area of 1.5 km^2, is covered by muddy and sandy sediments, and is not deeper than 50 m. The soft bottom is colonized by a diverse community of sessile animals (Klöser *et al.* 1994).

Animal collection: ascidians were collected between December 1, 1994-February 6, 1995, and December 23, 1995-February 21, 1996.

Specimens were collected by SCUBA diving at dephts between 15 and 30 m, over three different types of substrate; E1: soft, muddy bottom; E2: hard bottoms (pebbles, gravel and rocks); and E3: moraine deposits (boulders, sand and gravel) (Fig. 1).

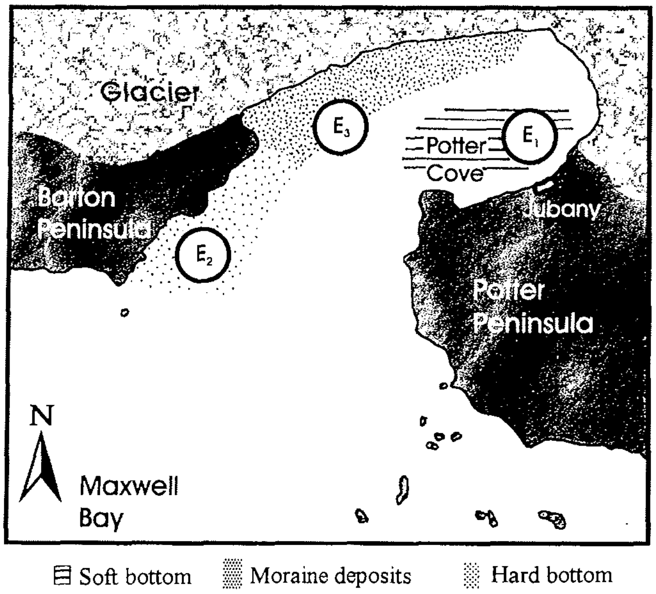

Fig. 1. Map of Potter Cove with the location of the sampling stations.

Specimens were fixed with 2,5% formaldehyde in sea water. Staining and mounting techniques have been described by Monniot & Monniot (1972).

The material collected has been deposited in the Cátedra de Anatomía Comparada, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba.

RESULTS AND DISCUSSION

The species found were *Aplidium radiatum* (Sluiter, 1906); *Synoicum adareanum* (Herdman, 1902); *Sycozoa gaimardi* (Herdman, 1886); *S. sigillinoides* Lesson, 1830; *Distaplia cylindrica* (Lesson, 1830); *Tylobranchion speciosum* Herdman, 1886; *Corella eumyota* Traustedt, 1882; *Ascidia challengeri* Herdman, 1882; *Cnemidocarpa verrucosa* (Lesson, 1830); *Styela wandeli* (Sluiter, 1911); *Dicarpa insinuosa* (Sluiter, 1912); *Pyura bouvetensis* (Michaelsen, 1904); *P. discoveryi* (Herdman, 1910); *P. obesa* Sluiter, 1912; *P. setosa* (Sluiter, 1905); *Molgula enodis* (Sluiter, 1912), and *M. pedunculata* Herdman, 1881. The majority of the species found have an Antarctic and Subantarctic distribution, but 8 species are endemic in Antarctica. These endemic species are *Aplidium radiatum, Styela wandeli, Dicarpa insinuosa, Pyura bouvetensis, P. discoveryi, P. obesa, P. setosa,* and *Molgula enodis* (Kott 1969, Monniot & Monniot 1983). In Potter Cove, areas of soft bottom (E1) and moraine deposits (E3) had the highest ascidian diversity (Table I) (Fig. 2).

Table I: Number of specimens for all species found in the different stations in Potter Cove.

Species	E1	E2	E3
Aplidium radiatum	7	-	10
Synoicum adareanum	-	2	8
Distaplia cylindrica	8	-	1
Sycozoa gaimardi	26	-	-
Sycozoa sigillinoides	1	-	-
Tylobranchion speciosum	18	-	-
Corella eumyota	17	-	5
Ascidia challengeri	20	-	18
Cnemidocarpa verrucosa	20	19	15
Styela wandeli	-	-	13
Dicarpa insinuosa	2	-	-
Pyura bouvetensis	-	-	3
Pyura discoveryi	8	-	-
Pyura obesa	-	-	3
Pyura setosa	4	-	4
Molgula enodis	10	-	7
Molgula pedunculata	22	27	25

E1; soft bottoms; E2: hard bottoms; E3: moraine deposits.

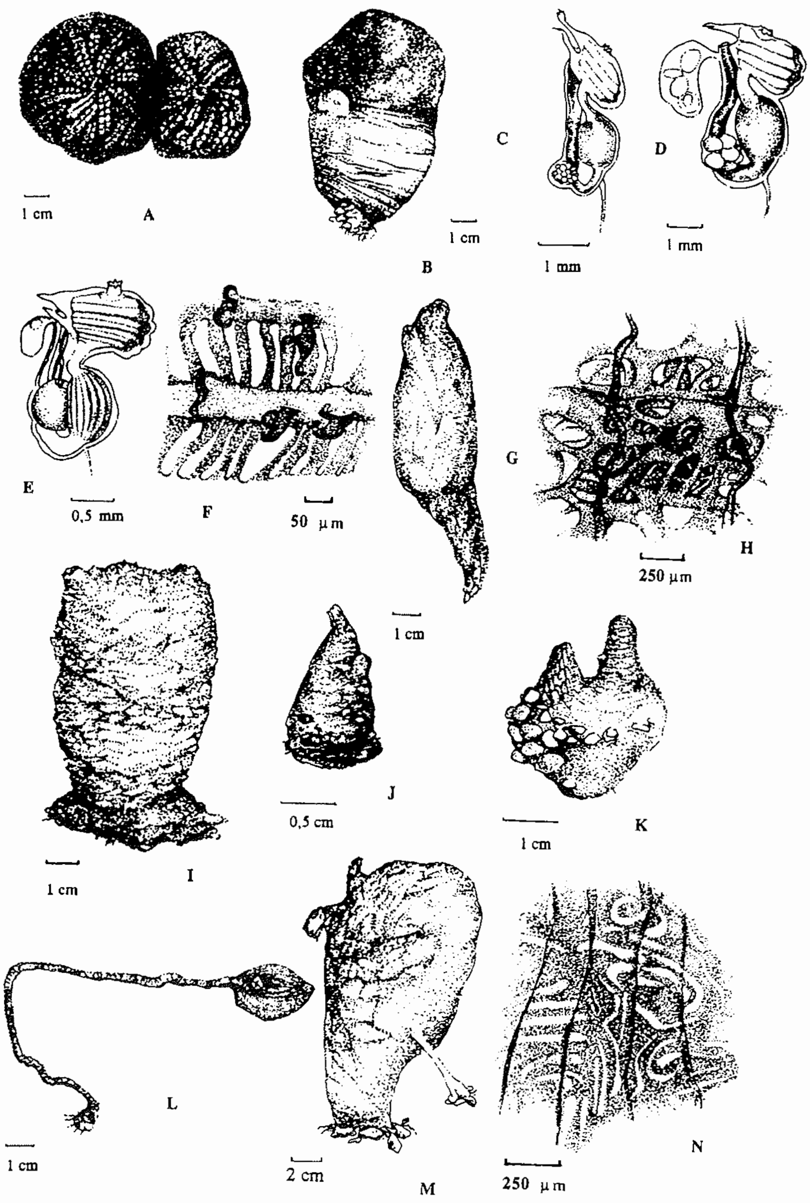

Fig. 2: A: *Aplidium radiatum*. External appearance. B: *Synoicum adareanum*. External appearance. C: *Sycozoa gaimardi*. Zooid. D: *Sycozoa sigillinoides*. Zooid. E: *Distaplia cylindrica*. Zooid. F: *Tylobranchion speciosum*. branchial sac. G: *Ascidia challengeri*. External appearance. H: *Corella eumyota*. Branchial sac. I: *Cnemidocarpa verrucosa*. External appearance. J: *Styela wandeli*. External appearance. K: *Pyura discoveryi*. External appearance. L: *Pyura bouvetensis*. External appearance. M: *Pyura obesa*. External appearance. N: *Molgula enodis*. Branchial sac.

E1 and E3 could be less stressed environments, with less disturbance and more available food amounts. The inner cove is more protected of iceberg disturbance than the outer parts, and high amounts of organic and inorganic matter are present in that area in summer, owing to meltwater inflow (Schloss *et al.* 1994). In stations with soft bottoms (E1) and moraine deposits (E3), the specimen were growing in patches around the largest solitary specimen. These patches can provide substrate for the settlement of other species, and epibiosis seems to be a common phenomenon there. A total of seven of the solitary species in these stations showed epibionts, such as bryozoans, red algae and ascidians. Colonial species were free of epibionts. However, there is a gradient of epibiosis in solitary ascidians: while stolidobranch ascidians *M. pedunculata, P. setosa and C. verrucosa* had most, phlebobranch ones *C. eumyota* and *A. challengeri* had few. Similarly, solitary ascidians were found to have more epibionts than other organisms examined in other areas including ascidians, bryozoans, coelenterates and sponges (Davis & White 1994). The firm test of some solitary ascidians provides a surface on which foulers are regularly established, mainly in areas where suitable substrate is not abundant and competence for substrate is important (Turon, 1988), as observed in E1. On the other hand, hard bottom areas (E2) had the lowest ascidian diversity. The specimens of *M. pedunculata* and *C. verrucosa* showed here a less patchy distribution, and no epibionts were found. Iceberg impact and substrate type could determine the differences among E1 and E2 in ascidian distribution and diversity.

The abscence of ascidians in the upper 15 m is assumed to be a result of ice, wave action and sediment input. Within this zone pennatulids and the bivalve *Laternula elliptica* are the dominant sessile benthic invertebrates. Besides physical disturbance, macroalgae foliage moved by waves and tides prevent the recruitment of ascidian larvae on hard bottoms and moraine deposits. The species *S. adareanum* and *P. obesa* showed an association with macroalgae, they are the only ascidian species living under foliage, but at depths where the waves and tidal effect do not cause a great movement of algae thalli.

Below 20 m ascidian abundance increased at all the stations examined within this study.

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REFERENCES

Davis A. R. & G. A.White, 1994. Epibiosis in a guild of sessile subtidal invertebrates in south-eastern Australia: a quantitative survey. J. Exp. Mar. Biol. Ecol. 177: 1-14.

Dayton P. K. , Robilliard G. A. & R. T. Paine, 1970. Benthic faunal zonation as a result of anchorice at Mc. Murdo Sound, Antarctica. - Antarctic Ecology Ed. M. W. Holgate Academic Press, London and N. York 1 : 244-257.

Hedgpeth J. W. , 1969. Introduction to Antarctic zoogeography in : Distribution of selected groups of marine invertebrates in waters south of 35° S latitude. - Antarctic Map Folio Ser., 11 : 1-9.

Klöser H., Mercuri G., Laturnus F., Quartino M.L & C.Wiencke, 1994. On the competitive balance of macroalgae at Potter Cove (King George Islands, South Shetlands). Polar Biol. 14: 11-16.

Kott P., 1969. Antarctic Ascidiacea I. - Antarct. Res. Ser., 13: 1-239.

Monniot C., 1965. Etude sistematique et évolutive de la famille des Pyuridae (Ascidiacea). - Mém. Mus. Natn. Hist. Nat., Paris 36 (A): 1-203.

Monniot C. & F. Monniot, 1972. Clé mondiale des genres d' Ascidies. - Arch. Zool. Exp. Gen. 113: 311-367.

Monniot C. & F. Monniot, 1983. Ascidies antarctiques et subantarctiques: morphologie et biogéographie. Mém. Mus. Natn. Hist. Nat., Paris, (A), 125 : 1-135.

Schloss, I., Ferreyra, G., Pinola, E., Mercuri, G. & A.Curtosi, 1994. Variación de la biomasa fitoplanctónica y del material particulado en suspensión en relación a algunos parámetros ambientales en Caleta Potter. Contrib. Inst. Antárt. Argent., 419, 17-30.

Svane Y. & C.M. Young, 1989. The ecology and behaviour of ascidian larvae. Oceanogr. Mar. Biol. Annu. Rev.,27: 45-90.

Turon X., 1988. Distribución ecológica de las ascidias en las costas de Cataluña e islas Baleares (Mediterráneo Occidental). Misc. Zool. 12: 219-236.

Habitat demands and zonation of benthic foraminifera in the Antarctic Potter Cove: First results

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Foraminifera are present in almost all marine ecosystems (HESSLER 1974, GOODAY 1986, HEEGER 1990). About 30.000 fossil and about 6.000 recent species have been identified, of which most of them are benthic (HEMLEBEN et al. 1989, WOLLENBURG 1992). Benthic foraminifera are protists which bear tests, reticulopods, and have alternating generations. They sometimes construct a single-chambered (unilocular) and more often multiple-chambered shells (multilocular)of either secreted calcium carbonate, cemented mineral particles or secreted organic material. The architecture of the tests varies broadly. Benthic foraminifera can contribute to a considerable fraction to the meiofaunal biomass and energy flow (GERLACH et al. 1985, ALTENBACH & SARNTHEIN 1989). Because of the good fossilization potential of their shells, foraminifera are important as bio-stratigraphic and paleo-oceanographic tracers (e.g. BOERSMA 1978, BERGER 1981, DOUGLAS & WOODRUFF 1981). Despite such significance, little attention has been paid to their environmental requirements and their interrelationships with other organisms (HEEGER 1990). The reaction of benthic foraminifera to seasonal variations in quality and quantity of food supply and their role in the marine food web remains largely unknown (DELACA et al. 1980). Most work on Antarctic benthic foraminifera has been conducted on deep water samples (ISHMAN & DOMACK 1994), whereas little has been done in shallow-water regions, to date (BERNHARD 1989).

The scope of the present study is to describe the role of benthic foraminifera in the sublittoral ecosystem of the Antarctic Potter Cove (for detailed maps of the Potter Cove area see 'introduction'). Community composition, seasonal and interannual variations in their distribution patterns, and the correlation of their patterns with biotic and abiotic parameters were sampled, and are currently further investigated at the home laboratory. Experiments address autecologic issues, e.g. mobility, physiology, reproduction, and settlement preferences. The investigations started in October 1996, and preliminary results are presented in this chapter.

During an initial expedition (October 1996-December 1996), samples were collected with a van-Veen-grab at stations distributed along a depth transect, (5m, 10m, 20m, 30m). The transect was located directly in front of the Dallmann Laboratory. Most sediment samples were fixed for later analyses of sediment parameters, population dynamics, large scale distribution, depth zonation, and cell physiology. Sediment cores that were taken by SCUBA divers, as well as small-scale vertical distribution patterns within the sediment, are currently evaluated at the home laboratory. First results show clear differences between soft and hard bottom areas of the Potter Cove. Inside soft bottom the highest foraminiferal density was recorded at a water depth of 20m (Fig. 1) which is primarily connected to the water depth depended grain size distribution. Hard bottom habitats appear unsuitable for the settlement of foraminifera. However, a plethora of foraminifera were found on other organisms or substrates. Epibenthic foraminifera were detected on red algae, ascidians, some crustaceans, sponges, and stones. At rocky shores, only single individuals were encountered, that were imported probably randomly by tidal currents.

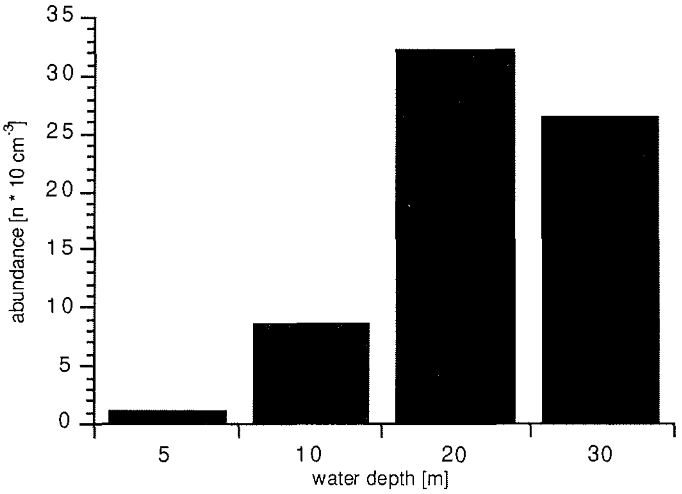

Fig. 1: Abundance of endobenthic foraminifera in front of the Dallmann Laboratory. 28.10.1996; foraminifera counted: 1025

Of all collected species 38% build their shells with agglutinated sand grains (Textuallariina). Foraminifera with organic shells (Allogromiina) contributed with 35%, and calcerous species (Miliolina) with 27% to total species number. However, in terms of abundance the calcerous species dominate.

To quantify benthic foraminifera movement through the sediment and their active selection of their habitat, selected laboratory experiments on their motility were performed. The experiments were conducted with *Pyrgo wiliamsoni* collected by SCUBA diving. This species attains a maximum size of 2mm. Initial results suggests, that *P. williamsoni* occurs in higher abundances in proximity to ascidians than in "ascidian-free" sediments. Consequently, these attached specimens were collected in combination with ascidians that were sampled with containers, and with sieving the sediment bycatch. A Petri dish was separated in 254 quadrats each of which measured $25mm^2$. Several individuals were placed together with silty sediment inside the dish and their tracks were measured in 1h intervals. Results demonstrate, that *P. williamsoni* is able to traverse up to16mm^2 per hour (Fig.2).

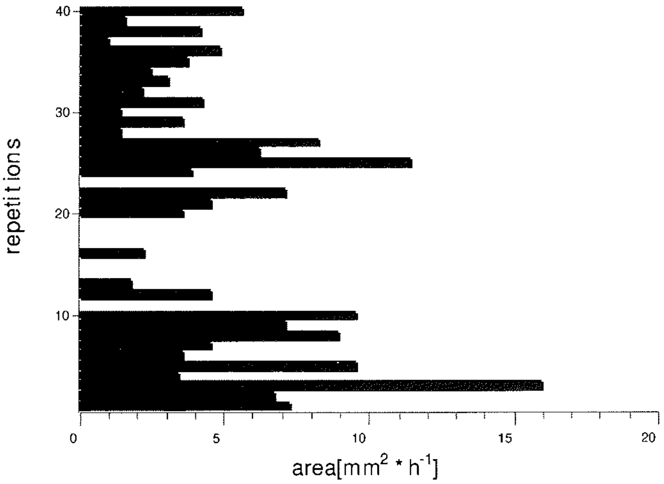

Fig. 2: Movement experiment with the foraminifera *Pyrgo williamsoni.* mean = 4,3 mm^2/h. n=40.

From our study we speculate that the foraminifera *P. williamsoni* is therefore able to return to favoured sediment depth after being displaced by larger burrowing animals.

In the Antarctic summer 1997/98, probing of the sediment by grab was continued and diving protocolls were expanded. In particular, the affinity of epibiontic foraminifera to special substrates will be examined. Several laboratory experiments on food physiology will be evaluated and the reproduction cycle of certain species will be investigated during long-term studies at the home laboratory in Kiel, Germany. Our preliminary results demonstrate that benthic foraminifera are more widespread within the Potter Cove and probably have a higher ecological relevance than initialy expected.

References

ALTENBACH & SARNTHEIN (1989): Productivity record in benthic Foraminifera. In: BERGER, W.H., SMETACEK, V.S., WEFER, G.: Productivity of the Ocean: Present and Past. Wiley & Sons: 255-269

BERNHARD, J.M. (1989): The distribution of benthic Foraminifera with respect to oxygen concentration and organic carbon levels in shallow-water Antarctic sediments. Limnol Oceanogr 34: 1131-1141

BERGER, W.H. (1981): Paleoceanography: the deep-sea record. In: EMILIANI, C. (ed.): The sea. The oceanic lithosphere. John Wiley, New York, Vol. 7: 1437-1519

BOERSMA, A. (1978): Foraminifera. In: HAQ, B.U. & BOERSMA, A. (eds.): Introduction to marine micropaleontology. Library of Congress Cataloging in Publication Data: 19-77

DELACA, T.E., LIPPS, J.J., HESSLER, R.R. (1980): The morphology and ecology of a new large agglutinated Antarctic Foraminifer (Textulariina: Notodendrodidae nov.) J Linnean Soc 69: 205-224

DOUGLAS, R.G., WOODRUFF, F. (1981): Deep-sea benthic Foraminifera. In: EMILIANI, C. (ed.): The sea. The oceanic lithosphere. John Wiley, New York, Vol. 7: 1233-1327

GOODAY, A.J. (1986): Meiofaunal foraminiferans from the bathyal Porcupine Seabight (northeast Atlantic): size structure, standing stock, taconomic composition, species diversity and vertical distribution in the sediment. Deep-Sea Res 33: 1345-1373

GERLACH, S.A., HAHN, A.E., SCHRAGE, M. (1985): Size spectra of benthic biomass and metabolism. Mar Ecol Prog Ser 26: 161-337

HEEGER, T. (1990): Elektronenmikroskopische Untersuchungen zur Ernährungbiologie benthischer Forminiferen. Ber SFB 313, Univ Kiel 21: 1-139

HEMLEBEN, CH., SPINDLER, M., ANDERSON, O.R. (1989): Modern Planktonic Foraminifera. Springer-Verlag, p 363

HESSLER, R.R. (1974): The structure of deep benthic communities from central oceanic waters. In: MILLER, C.B., (ed.): The Biology of the Oceanic Pacific. Oregon State Univ Press, Corvallis: 79-93

ISHMAN, S.E., DOMACK, E.W. (1994): Oceanographic controls on benthic foraminifers from the Bellingshausen margin of the Antarctic Peninsula. Mar Micropaleontol 24: 119-155

WOLLENBURG, J. (1992): Zur Taxonomie von rezenten benthischen Foraminiferen aus dem Nansen Becken, arktischer Ozean. Ber Polarforsch 112: 1-137

EPIFAUNAL COMMUNITIES IN POTTER COVE, KING GEORGE ISLAND, ANTARCTICA.

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Sub-littoral benthic ecology in Antarctica is a relatively new field of research. The majority of early studies, were made on systematics and on deep-water benthos. During the last two decades, quantitative analyses of the Antarctic benthos have been carried out in various regions (Barthel and Gutt 1992, Dayton et al. 1974, Gallardo et. al 1977, Gerdes et al. 1992, Kirkwood and Burton 1988, Mühlenhardt-Siegel 1988, Sáiz-Salinas et al. 1997). One of the emergent features of these works, is the richness in terms of diversity and biomass of Antarctic benthos, especially in shallow waters. Another peculiarity is the widespread dominance of sessile epifaunal groups mainly sponges (Dayton et al. 1974). But polychaetes, molluscs, echinoderms and crustaceans can dominate as well (White 1984, Starmans 1997). However comparisons of all results is usually difficult because of the use of different sampling methods (dredges, trawls, corers, photographs, etc.) and parameters (biomass as wet weigth or dry weigth, densities, percentaje cover etc.). Althougth the study of the community structure along a natural environmental gradient may not provide conclusive insights into the processes that form this pattern, it is a necessary step before studies can be undertaken to reveal the processes themselves (Turon 1990). A variety of factors have been proposed to influence the community structure in Antarctic benthos. The principal ones are substrate type, physical disturbs caused by ice action, phytoplancton biomass, predation, competition, oxygenation, current speed, and pollution (Dayton et. al 1970, Dayton and Oliver 1977, Hedgpeth 1969, Kirkwood and Burton, Platt 1978, Sahade et al. 1998). The aim of the present study is to describe the benthic community structure in Potter Cove in relation to physical factors as depth and substrate types, and to discuss about the principal factors that may determine the observed patterns.

Investigation area

Potter Cove (62° 14' S, 58° 38' W), where the Argentine station Jubany and the Argentine-German Dallmann Laboratory are situated, is a tributary inlet close to the entrance of Maxwell Bay, one of the two large fjords of King George Island (Fig. 1). The Cove is divided into a mouth and an inner part. The mouth has an area of about 3 km^2 and is bordered by steep slopes down to 100 m to the

North and by a broad intertidal platform to the Southwest. Hard bottoms and macroalgae dominate this area (Klöser et al. 1994). The inner cove has an area of 1.5 km^2, is covered by muddy and sandy sediments, and is not deeper than 50 m.

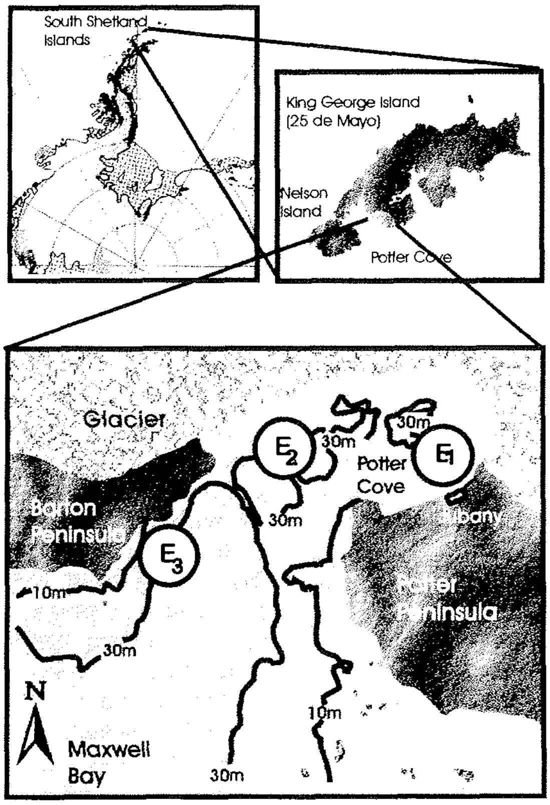


Fig. 1: Map of Potter Cove and its location in King George Island and Antarctica. Sampling stations E_1 (soft bottom), E_2 (hard bottom) and E_3 (moraine deposites) are highlighted.

Methods

Investigations were carried out in the austral summers 1994/95 and 1995/6. Raw data were obtained from photo-transects taken in each of the subtrates types presents in the Cove along a 50 m line at particular depth profiles, 15, 20, 25 and 30 m, covering 150 m^2 in total. The photographs were taken at 1 m intervals, using a Nikonos V camera with a 15 mm lens and a Subtronic SF 3003 TTL strobe, both mounted on an aluminium "quadrapod" (50 x 50 cm; Kühne 1992). Samples of the fauna were taken for identification. Photographs were projected onto grids of 100 random points and the number of points underlying each organism were counted to estimate percentage cover and bare substratum. All the animals in each photograph were counted and the total number divided by the area sampled was used to estimate densities. This photographic technique allow a fast data acquisition in the field, providing information about habitat, abundance, percentage cover, and species associations of benthic assemblages. However may underestimate abundances of small, cryptic, associated with macroalgae thalli and highly mobile individuals.

Data analysis

We analysed bathymetric variation in community structure by comparing species richness (S'), Shannon-Wiener diversity index (H'), and evenness index (J'). These indexes were calculated separately for each sample, in order to estimate means and standard deviations. The values of S', H' and J' for different depths were compared using one-way analyses of variance (ANOVA). Homogeneity of variances were tested using Cochran´s C test.

RESULTS

We recorded a total of 30 taxa (Table 1), the majority being ascidians and echinoderms. The quantitative results of each station are shown in Figs. 2-4. A brief analysis of the stations is presented below.

Table 1: List of Taxa sampled and abbreviations used in figures, x indicates the presence of the taxa in each of the stations sampled.

	Taxa	Abbreviation	E_1	E_2	E_3
Phaeophita	*Desmarestia sp.*	D.sp.		x	x
	Himantotalus grandifolius	H.g.		x	x
	Unidentified	Phe.			x
Rhodophita		Rho.		x	x
Ascidiacea	*Molgula pedunculata*	M.p.	x	x	x
	M. enodis	M.e.		x	x
	Aplidium radiatum	A.r	x	x	x
	Ascidia challengeri	A.c.	x		x
	Corella eumyota	C.e.	x		x
	Cnemidocarpa verrucosa	C.v	x	x	x
	Pyura setosa	P.s.	x		x
	P. obesa	P.o.		x	x
	Tilobranchion speciosum	T.s.	x		
	Sicozoa gaimardi	S.g.	x		
	Distaplia cylindrica	D.c.	x		x
	Sinoycum adareanum	S.a.			x
	Styela wandeli	S.w.			x
Porifera		Por.	x		x
Pennatulids		Pen.	x		x
Gastropoda	*Nacella concina*	N.c.		x	x
	Unidentified	Gas.	x	x	x
Bivalvia	*Laternula elliptica*	L.e.	x	x	x
Asteroidea	*Diplasterias brucei*	D.b.	x	x	
	Unidentified	Ast.	x	x	x
Ophiuroidea	*Ophionotus victoriae*	O.v.	x	x	
Echinoidea	*Sterechinus neumayeri*	S.n.	x	x	x
Nemertina	*Parborlasia corrugatus*	P.c.	x		
Polychaeta		Pol.	x		x
Actiniaria		Act.	x		
Briozoa		Bri.		x	x

Station 1(Soft bottom, Fig. 2):

A pattern of depth zonation became evident. At 15 m the situation was characterized by the low number of taxa (9 in total), the high percentage of bare substratum (95%), and the dominance of pennatulids and the bivalve *Laternula* *elliptica*. At 20 m there was a marked shift in community structure, the ascidian *Molgula pedunculata* becoming the dominant species. Also there was an increase in the number of taxa (12) and a decrease in the percentage of bare substratum (85 %). This trend was kept down to 30 m (14 taxa and 81% bare substratum at 25 m). At 30 m we registered the highest number of taxa (20) and the lowest percentage of bare substratum (65%). The community was dominated by 6 ascidians species: *M. pedunculata*, *Aplidium radiatum*, *Corella eumyota*, *Ascidia challengeri*, *Cnemidocarpa verrucosa*, and *Pyura setosa*. Except for *A. radiatum*, the other species are solitary, *M. pedunculata* being the most abundant organism (16.32 Individuals/m^2).

The mean species richness S' showed significant increments with depth (ANOVA; F-ratio=10.923, P<0.01), as well as the mean values of H' (ANOVA; F-ratio=14.014, P<0.01) and J' (ANOVA; F-ratio=4.624, P<0.01) (Fig. 5). The mean values of S' increased steadily from 15 to 30 m, whereas H' and J' values showed two extreme situations at 15 and 30 m and a transition between 20 and 25 m, where differences were not significant (Fig. 5).

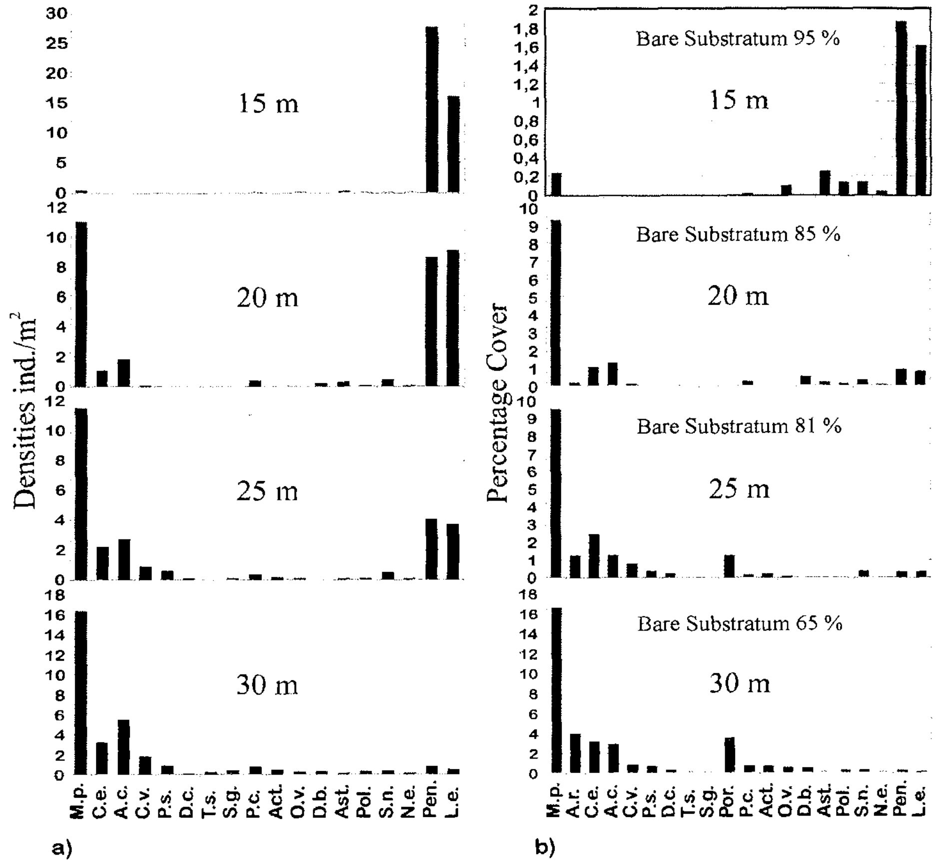


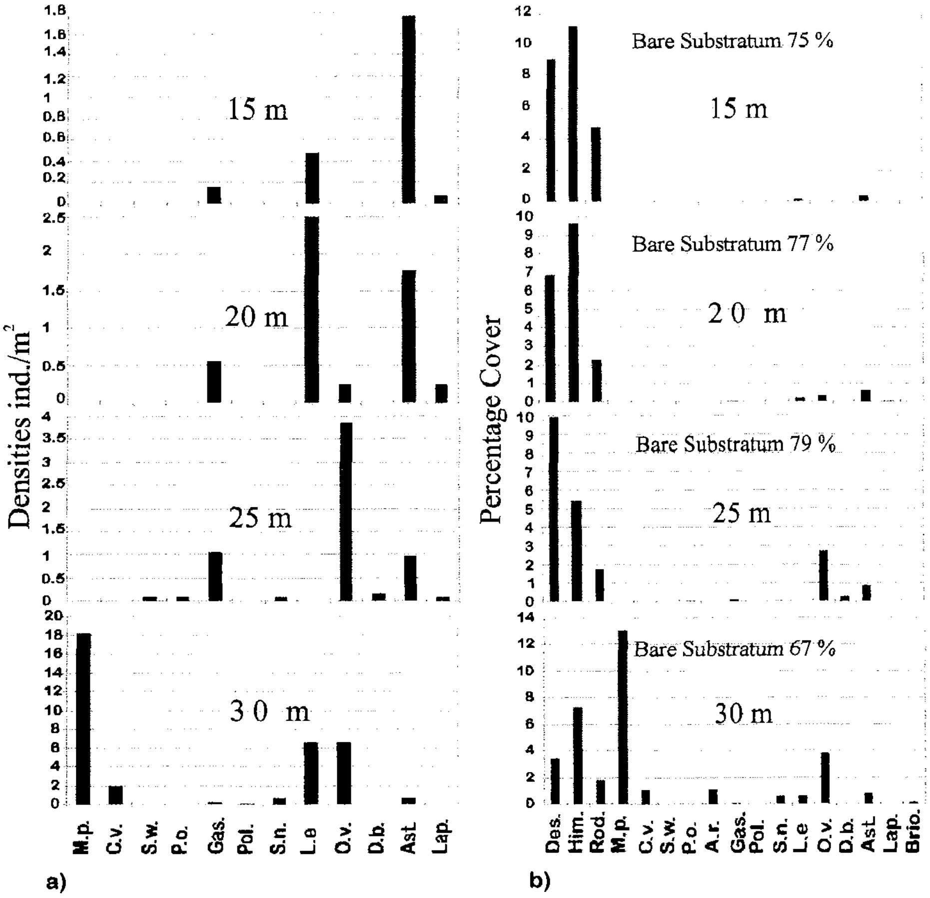
Fig. 2: Station 1: a) Abundance (percentage cover) of the taxonomic groups present at each depth profile. Empty columns indicate the absence of the taxon at a given depth.

b) Densities (ind./m^2) of the taxonomic groups present at each depth profile. Empty columns indicate the absence of the taxon at a given depth.

Station 2 (Hard bottom, Fig. 3):

Algae were the dominant group, especially *Desmarestia sp. and Himantotalus grandifolius*, up to 25 m. The number of taxa were low (5 to 9 between 15 and 25 m) and the percentage of bare substratum were lower than in soft bottoms. Other importants groups presents were Ophiuroidea, Asteroidea, the limpet *Nacella concina* and Gastropoda. At 25 m one of the two ascidians species associated with macroalgae thally, *Pyura obesa* was also present. At 30 m there is a shift in community structure becoming dominant animal groups especially the ascidians *Molgula pedunculata*, *Aplidium radiatum* and *Cnemidocarpa verrucosa*, but the number of taxa is low compared with other stations.

The mean species richness S' showed significant increments with depth (S' ANOVA, F-ratio = 24.063, P < 0.01). The diversity indices did not vary significatively (H' ANOVA, F-ratio = 1.861, P > 0.01, J' ANOVA, F-ratio = 3.140 P > 0.01), because of the way that the great algae abundance affect these indices, however the differences observed in the Fig 5 can be considered relevants.



a) b)

Fig. 3: Station 2: a) Abundance (percentage cover) of the taxonomic groups present at each depth profile. Empty columns indicate the absence of the taxon at a given depth.

b) Densities (ind./m^2) of the taxonomic groups present at each depth profile. Empty columns indicate the absence of the taxon at a given depth.

Station 3 (Moraine deposits, Fig. 4):

This was a transition station, with some characteristics similar to Station 1 and other ones similar to Station 2. At 15 m algae were dominants, especially *Himantotalus grandifolius* with a high percentage cover (33 %), the pattern of a low number of taxa is repeated in this station. At 20 m algae are still dominant, but there is a slight increase in animal groups. The two ascidians associated with macroalgae thalli *Pyura obesa* and *Sinoycum adareanum* were present. At 25 m a situation similar to 20 m was found. Finally, at 30 m we observed a rich community, although dominated by algae, but with a high proportion of animals. The most abundants groups were the ascidians *Cnemidocarpa verrucosa* and *Molgula pedunculata*, Porifera, Echinoidea, Asteroidea and Briozoa. The mean species richness S' showed significant differences related to depth (S' ANOVA, F-ratio = 20.554, P < 0.01), as well as diversity indices (H' ANOVA, F-ratio = 26.752, P < 0.01; J' ANOVA F-ratio = 13.962, P < 0.01).

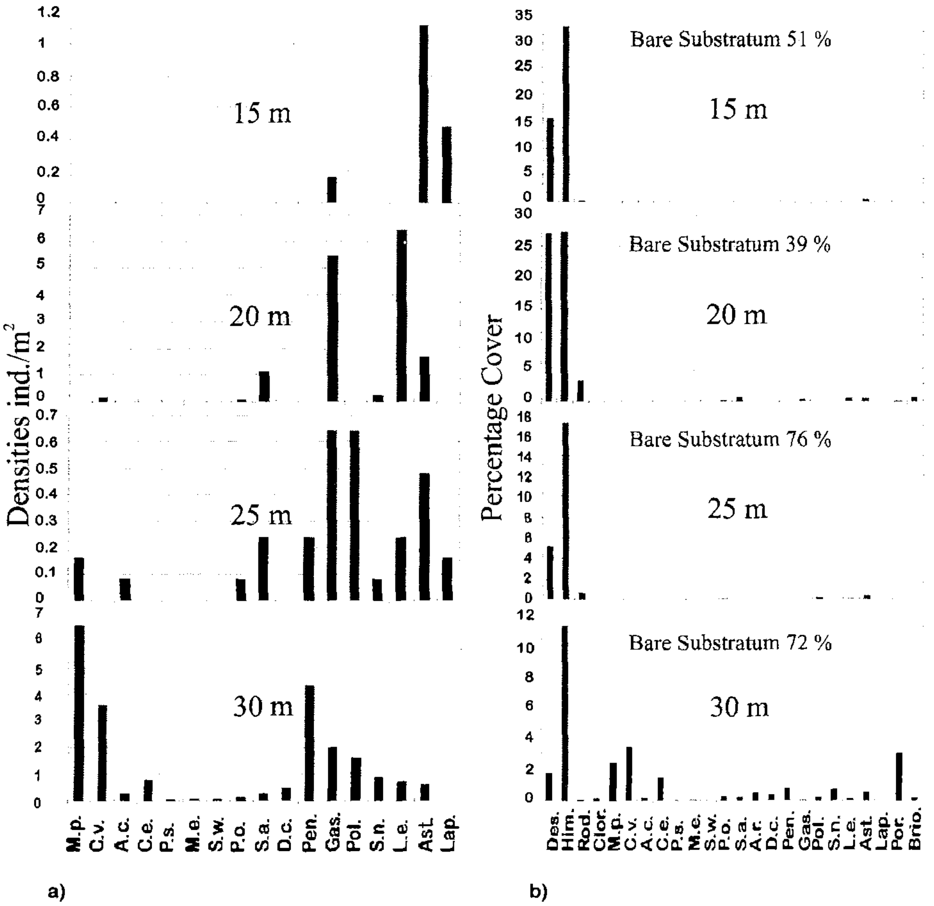


Fig. 4: Station 3: a) Abundance (percentage cover) of the taxonomic groups present at each depth profile. Empty columns indicate the absence of the taxon at a given depth.

b) Densities (ind./m^2) of the taxonomic groups present at each depth profile. Empty columns indicate the absence of the taxon at a given depth.

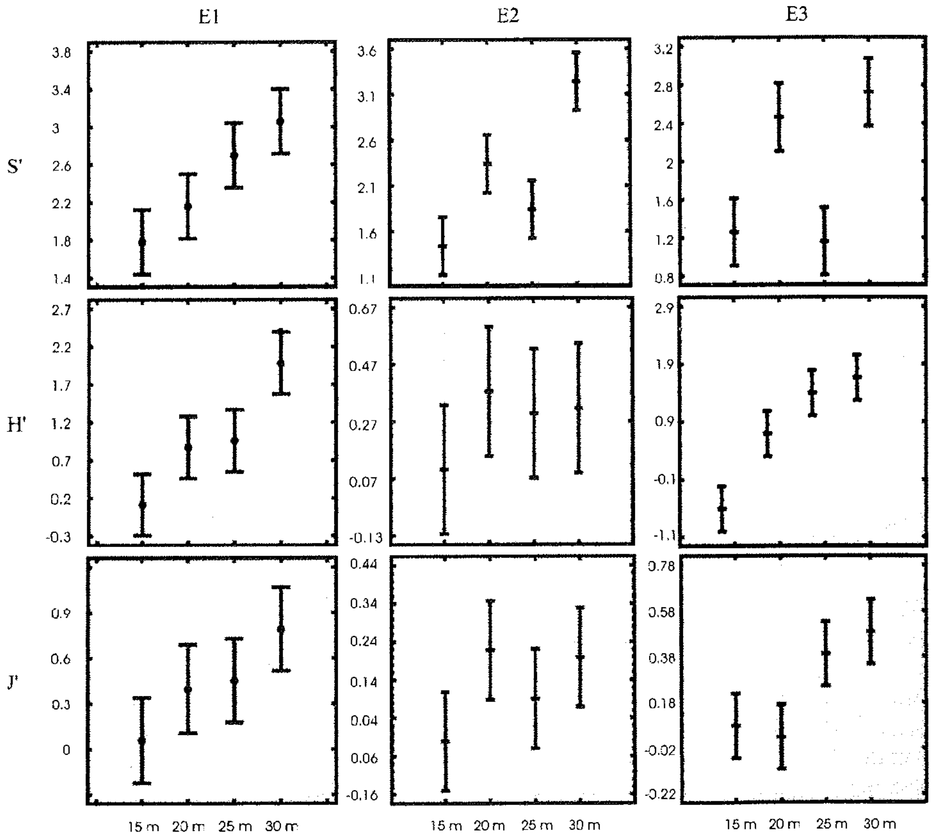


Fig. 5: Mean values of species richness S', H' and J' in relation to depth of each sampled station (Scheffe intervals are represented).

DISCUSSION

There were marked changes in community structure in relation to depth and to substrate types. In soft bottom the pattern of low diversity found in shallow waters at 15-20 m may be explained, by the destructive ice action, icebergs and anchor ice. We have observed deep depressions in the bottom, down to 20 m, caused by icebergs. Such impacts remove all the bottom fauna over extensive areas. Moreover anchor ice formation, is able to remove the stablished fauna in its influence area (Dayton et al. 1970). Although we never observed this phenomenon, it has been described by divers who worked during the winter season. These phenomena may account for the low diversity and high percentage of bare substratum observed at 15 m. The relatively high density of *L. elliptica* at 15 m may be explained by their capacity to bury themselves, enabling them to avoid the ice impact. The pennatulids are also very abundant in this areas due to their high growth rates with a nearly complete generation cycle in one year, thus acting as opportunistic species with an r-strategy (Kowalke unpub. data). The success of these two differents strategies, one infaunal and the other opportunistic, with a rapid colonization of the disturbed space and high growth rates, support the idea of an area highly affected by ice action.

In hard bottom and moraine deposits macroalgae dominate in shallow waters up to 20-25 m. In these areas the presence of fauna is mainly reduced to movile organisms, the absence of sessile organisms may be due to the effect of macroalgae foliage moved by waves and tides that could prevent the development of most of the sessile fauna. They are, in addition, more exposed to the icebergs impact than the soft bottom area, which toghether with algae effect may cause the low sessile fauna diversity patterns observed here. At 30 m we registered the most riches and diverses communities in all the stations. At this depth the ice action is very unlikely and the algae foliage is scarce compared with shallower waters. These factors allow the development of a rich animal community mainly regulated by biological factors (Fig. 5). Station 2 had a lower diversity than the other stations, its community was dominated by three ascidians species the solitaires *Molgula pedunculata* and *Cnemidocarpa verrucosa* and the colonial *Aplidium radiatum*. These were the unique ascidians that colonized all the subtrate types presents in the cove. The other stations were also dominated by ascidians especially *M. pedunculata* and with important proportions of other groups as Porifera, Asteroidea and Echinoidea.

These findings demonstrate the good competitive habilities of ascidians which also rank very high in a hierarchical classification among other organisms in numerous benthic associations (Osman 1977; Russ 1982; Quinn 1982; Sebens 1986; Turon 1990). However, the Potter Cove community is the first described Antarctic bethic comminity dominated, in terms of density and percentage cover, by ascidians. In other Antarctic communities, ascidians were important members but they never were dominant (Galéron et. al 1992, Gerdes et. al 1992, Jazdzewski et. al 1986, Kirkwood and Burton 1988, Mühlenhardt-Siegel 1988) except for the case of Livingston and Deception Islands where ascidians were the most important organisms in terms of biomass (Sáiz-Salinas et al. 1997).

ACKNOWLEDGEMENTS

We are extremely grateful to the members of Jubany base, especially to our diving companions Augusto Fernández, Oscar Rillos and Esteban Andrade for their field assistance. This work was possible thanks to the CONICET, the Instituto Antártico Argentino (IAA) and the Alfred Wegener Institut (AWI) for the logistic support.

BIBLIOGRAPHY

Barthel D, Gutt J (1992). Sponge associations in the eastern Weddell Sea. Antarc. Sci. 4:137-150

Dayton PK, Oliver JS (1977). Antarctic soft-bottom benthos in oligotrophic and eutrophic environments. Science. N.Y. 197: 55-58

Dayton P K, Robilliard G A, Paine R T (1970). Benthic faunal zonation as a result of anchor ice at McMurdo Sound, Antarctica. In: Holdgate MW (ed.) Antarctic Ecology 1. Academic Press. 244-25

Dayton P K, Robilliard G A, Paine R T, Dayton L B (1974). Biological accommodation in the benthic community at McMurdo Sound, Antarctica. Ecol. Monogr. 44:105-12

Galéron J, Herman RL, Arnaud PM, Arntz WE, Hain S, Klages M (1992). Macrofaunal communities on the continental shelf and slope of the southeasthern Weddell Sea, Antarctica. Polar Biol. 12: 283-29

Gallardo VA, Castillo JC, Retamal MA, Yanez A, Morano HJ, Hermosilla JG (1977). Quantitative studies on the soft bottom macrobenthic animal communities of shallow Antarctic bays. In: Llano GA (ed) Adaptations within Antarctic ecosystems. Proc. 3rd SCAR Symp Antacrt. Biol. Smithsonian Institution, Washington DC, pp 361-387

Gerdes D, Klages M, Arntz WE, Herman RL, Galeron J, Hain S (1992). Quantitative investigations on macrobenthos communities of the southeastern Weddell Sea shelf based on multibox corer samples. Polar Biol. 12: 291-301

Hedgpeth J W (1969). Introduction to Antarctic zoogeography. In: Distribution of selected groups of marine invertebrates in waters south of 35º latitude. Antarctic Map Folio Series 11 :1-9

Jazdzewsky K, Jurasz W, Kittel W, Presler E, Sicinski J (1986) Abundance and biomass estimates of the benthic fauna in Admiralty Bay, King George Island, South Shetland Islands. Polar Biol. 6: 5-16

Kirkwood J M, Burton H R (1988). Macrobenthic species assemblages in Eljis Fjord, Vestfold Hills, Antarctica. Mar. Biol. 97 : 445-457

Klöser H, Mercuri G, Laturnus F, Quartino ML, Wiencke, C (1994). On the competetive balance of macroalgae at Potter Cove (King George Island, South Shetlands). Pol. Biol. 14:11-16

Mülhenhardt-Siegel U (1988). Some results on quantitative investigations of macrozoobenthos in the Scotia Arct (Antarctica). Polar Biol. 8: 241-24

Osman R W (1977). The establishment and development of a marine epifaunal community. Ecol. Monogr. 47:37-63

Quinn J F (1982). Competitive hierarchies in marine benthic communities. Oecologia. 54:129-135

Russ G R (1982). Overgrowth in a marine epifaunal community: competitive hierarchies and competitive networks. Oecol. 53: 12-19

Sahade R, Tatián M, Kowalke J, Kühne S, Esnal G (in press). Benthic faunal associations on soft substrates at Potter Cove, King George Island Antarctica. Polar Biol.

Sáiz -Salinas J I, Ramos A, García F J, Troncoso J S, San Martín G, Sanz C, Palacin C (1997). Quantitative analysis of macrobenthic soft-bottom assemblages in South Shetland waters (Antarctica). Polar Biol. 17 : 393-400

Sebens K P (1986). Spatial relationships among encrusting marine organisms in the New England subtidal zone. Ecol. Monogr. 56: 73- 97

Starmans, A. (1997). Vergleichende Untersuchungen zur Ökologie und Biodiversität des Megaepibenthos des Arktis und Antarktis. Rep. Pol. Res. 250: 140pp

Turon X (1990). Distribution and abundance of ascidians from a locality on the northeast coast of Spain. Mar. Ecol. 11:291-30

White MG (1984). Marine benthos. In Laws RM (Ed) Antarctic Ecology, vol 2. Academic Press, London, pp 421-461.

Meiofauna study in the Potter Cove - Sediment situation and resource availability for small crustaceans (Copepoda and Peracarida)

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Up to now meiofauna has not been studied in Potter Cove. But as it plays a very important role in the system of benthic communities due to its biomass, its degradation activities and as prey, it has to be taken into account when modelling the ecosystem. Focussing on harpacticoid copepods, this study has to deal with taxonomical problems first for the numerous new species to be found in front of JUBANY.

Studied sites and methods

This study was carried out in Potter Cove (62°14'S, 58°40' W) at King George Island, South Shetland Islands, Antarctica. A detailed description of the site is given by Klöser and Arntz (1994). The two depth transects presented here were sampled by scuba diving at 5 m, 10 m, 20 m, and 30 m between 01.02.96 and 09.02.96. Transect 1 is located in the inner cove starting from "Casa Bomba". Transect 2 lies at the ridge between inner and outer cove facing "Punta Elefante".

Six sediment corers of 80 cm^2 each were randomly pushed into the sediment at each depth station and brought to the surface as undisturbed as possible. The upper 3 cm of oxidized sediment layers of three sediment cores were frozen for biochemical and grain size analysis, the upper 3 cm sediment layers of the remaining three cores were preserved in 5 % formalin. Meiofauna was extracted from sediment samples by a centrifugation series with a colloidal silica polymer (Ludox). Grain size analysis was conducted only for the inorganic sediment components by wet-sieving through a series of meshes (mesh sizes see fig. 1). Total organic matter (TOM) of the upper 3 cm sediment layer was determined by 4 h combustion at 500 °C. Contents of organic carbon and nitrogen were measured using a C/N analyzer.

Meiofauna and its habitat

Transect 1 in the centre of Potter Cove is dominated by silt and clay sediments because of its protected location. The deeper sampling stations of this transect show little or no disturbance by currents and are a stable habitat not affected by icebergs again and again. In contrast to transect 2 the deeper stations of transect 1 can be described as a "low energy" environment (see fig. 1). The second transect is situated at the ridge between inner and outer cove which forms a natural barrier against large icebergs from outside the cove. Therefore it is an exposed area with mainly sandy sediments at least in the uppermost stations. Strong near bottom currents are always present. Their inward or outward movement depends on the direction of dominating winds that affect surface currents (Klöser and Arntz, 1994).

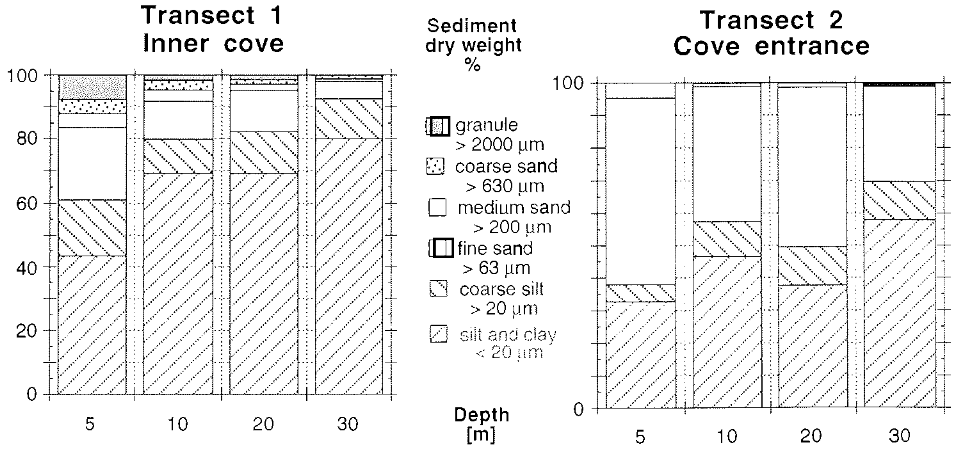

Fig. 1: *Dry weight fractions in the upper 3 cm sediment layer after sieving through a series of meshes at different depths of transect 1 (Inner cove) and transect 2 (Cove entrance)*

The total organic matter (TOM) along the two transects varies between 4.4 % and 6.15 % of the dry weight for the upper 3 cm layer of the sediment. The difference between the inner cove and the cove entrance at 10 m depth is due to the sampling in a detritus rich depression in transect 2 (fig. 2).

Organic carbon and nitrogen contents in contrast to mere TOM measurements give an impression of the quality of the organic sediment component. The C/N ratio is important in determining wheter the organic material consists only of detritus (in this case macroalgal material grinded by ice action) or of mainly living material (bacteria, microalgae, meiobenthos). Transect 1, although showing a tendency to a decreasing C and N content with depth, is characterized by a smaller C/N ratio as compared to transect 2 (fig. 2). Observations of a dense mat of diatoms on the ground have been made while diving at stations of transect 1. The organic material on this transect is dominated by microalgae. In contrast the sediments of transect 2 are covered with macroalgal detritus which causes higher C/N ratios and which has also been observed while diving. Shredded kelp material originating from the northern rocky shores of Potter Cove is deposited in depressions with little exposure to currents. Liebezeit and von Bodungen (1987) have pointed out that shallow water macroalgae in Bransfield Strait play a very important role as source of organic material. Macerated macroalgae can be found even in deep sea sediment traps and on the deep sea floor itself. In wintertime when ice action is high macroalgae present C/N ratios of about 10 (Rosell and Srivastava, 1985) and even summer thalli with very high C/N ratios of 30 can rapidly be degraded to values of around 10 by bacterial colonization (Reichardt and Dieckmann, 1984). Due to this high carbon input the C/N ratio along transect 2 is generally higher than along transect 1 where sedimentation of macroalgal detritus does not occur.

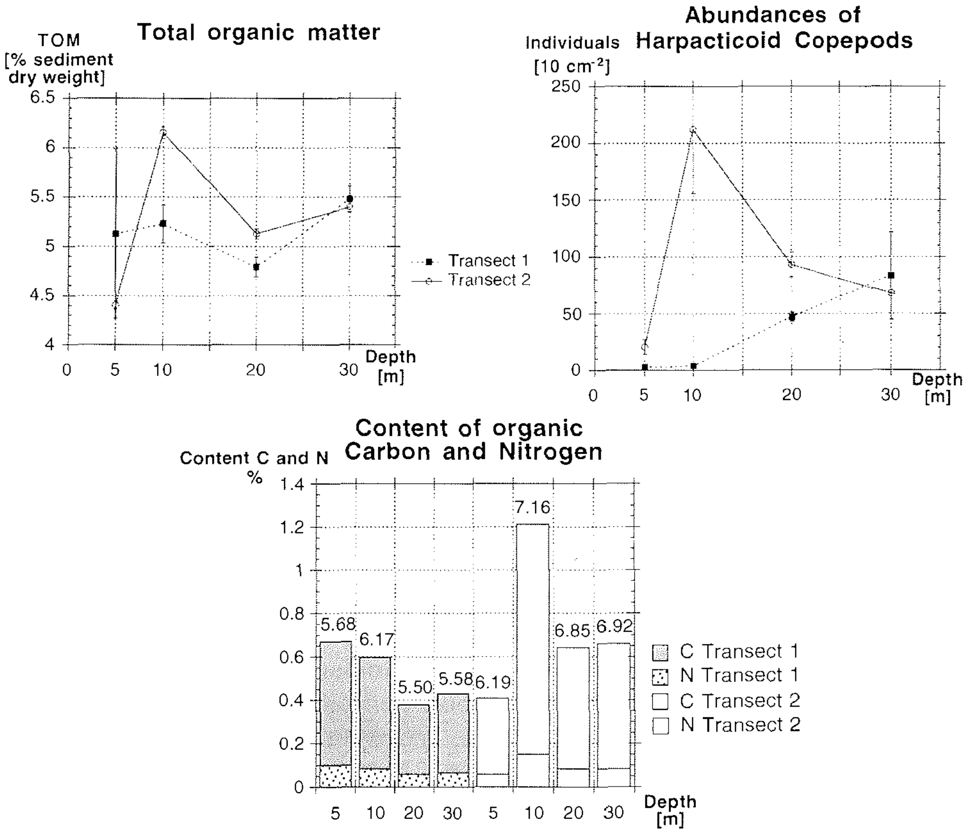

Fig. 2: *Total organic matter, abundances of harpacticoid copepods and content of organic carbon and nitrogen (C/N ratio is given above bar of each depth station) in the upper 3 cm sediment layer along transect 1 (Inner Cove) and transect 2 (Cove entrance) at the depths of 5 m, 10 m, 20 m, and 30 m*

The content of organic carbon and nitrogen in the sediments of both transects is generally low and comparable to deep sea conditions. Richardson et al.

(1995) found 0,18 % to 0,72 % of organic carbon and equally low percentages for organic nitrogen in sediments of the Puerto Rico Trench at 8000 m depth. As a consequence, these regions are very sparsely inhabited by macro- and meiofauna. Alongi (1990, 1992) postulates that density, biomass and size of macro- and meiofauna in the deep sea as well as in shallow waters depend on the availability of organic matter and its quality as well as on physical disturbances. The transects analyzed here clearly show both effects (fig. 2): While the high TOM availability at 10 m on transect 2 leads to a very high harpacticoid copepod abundance despite its low quality (C/N ratio 7.16), higher quality of organic matter on the deeper stations of transect 1 (C/N ratio 5.5 to 5.58) supports greater individual numbers with increasing depth and less physical disturbances even at low TOM concentrations.

Peracarida

In this study only the meiofauna-sized individuals of Peracarida are considered. Again the two transects show obvious differences due to sediment components and habitat preference of Peracarida (fig. 3). Cumacea can be found mainly in the soft sediments along transect 1 and at the deepest station of transect 2. Amphipoda prefer the sandy sediments with a higher content of organic matter especially the detritus rich depression at 10 m on transect 2. Tanaidacea are found exclusively on silty sediments and are more abundant only at deeper stations (30 m transect 1).

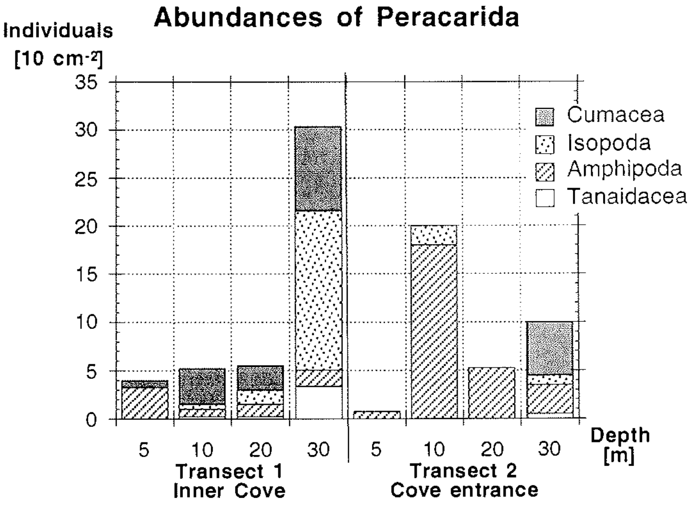

Fig. 3: *Abundances of Peracarida (Cumacea, Isopoda, Amphipoda, Tanaidacea) in the upper 3 cm sediment layer along transect 1 (Inner cove) and transect 2 (Cove entrance)*

Isopoda do not show any special preference for any sediment component but seem to be nutrition-bound choosing habitats with high TOM.

Remarks on *Pseudotachidius jubanyensis*, Veit-Köhler et Willen (in press)

This new species of the family Thalestridae (Harpacticoida, Copepoda) is very different from the other harpacticoids in Potter Cove. Its extreme body size with a length of up to 1 mm in the adult female and of 0.8 mm in the adult male is in contrast to the other harpacticoid copepods found in the same samples with a length of only 0.4 mm. It prefers low energy environments with a low C/N ratio at the deeper stations of transect 1. Along transect 2 it can be found only at a depth of 30 m. In general its abundances are very low with a maximum of 7 individuals per 10 cm^{-2} at 30 m on transect 1. Other harpacticoid copepods at this station have an abundance of 83 individuals per 10 cm^{-2}. But calculations of body volumes per sediment unit including also developmental stages of *Pseudotachidius jubanyensis* reveal that: The 7 individuals above mentioned have a total body volume of 239.32 nl while all other 83 copepods together have a body volume of 241.86 nl. The ecological role of *Pseudotachidius jubanyensis* is dealt with in a forthcoming paper including the description of the new species (Veit-Köhler and Willen, in press).

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References

Alongi, D.M. (1990): The ecology of tropical soft-bottom benthic ecosystem. Oceanography and Marine Biology Annual Reviews (28): 381-496

Alongi, D.M. (1992): Bathymetric patterns of deep-sea benthic communities from bathyal to abyssal depths in the western South Pacific (Solomon and Coral Seas). Deep-Sea Research (39): 549-565

Klöser, H. and W.E. Arntz (1995): RASCALS (Research on Antarctic Shallow Coastal and Litoral Systems) Untersuchungen zur Struktur und Dynamik eines antarktischen Küsten-ökosystems. Polarforschung 64 (1): 27-41.

Liebezeit, G. and B. von Bodungen (1987): Biogenic fluxes in the Bransfield Strait: planktonic versus macroalgal sources. Mar. Ecol. Prog. Ser. (36): 23-32

Reichardt, W. and G. Dieckmann (1984): Kinetics and trophic role of bacterial degradation of macroalgae in Antarctic coastal waters. In: Siegfried, W.R., Condy, P.R., Laws, R.M. (ed.) Antarctic nutrient cycles and food webs. Springer Verlag, Berlin, p. 115-122

Richardson, M.D., Briggs, K.B., Bowles, F.A., Tietjen, J.H. (1995): A depauperate benthic assemblage from the nutrient-poor sediments of the Puerto Rico Trench. Deep-Sea Research (42): 351-364

Rosell, K.-G. and L.M. Srivastava (1985): Seasonal variations in total nitrogen, carbon and amino acids in *Macrocystis integrifolia* and *Nereocystis luetkeana* (Phaeophyta). J. Phycol. 21: 304-309

Veit-Köhler, G. and E. Willen (in press): *Pseudotachidius jubanyensis* sp. nov. (Copepoda: Harpacticoida): A remarkable species from subantarctic shallow waters and its ecology.Senckenbergiana maritima

On the Distribution Patterns and Density of the Antarctic Infaunal Bivalve *Laternula elliptica* in Potter Cove, King George Island, Antarctica.

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The bivalve *Laternula elliptica* (King & Broderip, 1831)(Laternulidae) is widely distributed in nearshore waters around the Antarctic Continent and islands. This common filter-feeding species burrows up to 50 cm deep in the sediment, grows to a shell length of 100 mm (Ralph & Maxwell, 1977) and reaches a high biomass of up to 5 kg wet wt. per m^2 (Hardy, 1972). Owing to body size, geographical distribution and biomass, *Laternula elliptica* is the most dominant member of the Antarctic infauna (De Laca & Lipps, 1976). It is also important for the position in the trophic web, playing an important role in the pelagic-benthic coupling through biodeposition. It enhances both organic and inorganic particle fluxes from the water column to the sea bed (Döering et al.,1986), with important output of nutrients through excretion (Kautsky & Evans, 1987) and has a potentially significant role in both the transportation and fate of contaminants in Antarctic marine coastal ecosystems (Vodopivez & Curtosi, 1994; 1997). In this first phase of the present study (not yet completed) some results on the distribution and density of *Laternula elliptica* in Potter Cove are presented and the role of influencing factors like depth, physical stress factors, grain size and organic matter content of surrounding sediments, food availability and competition with other members of the community, was assessed and later discussed.

Investigation area

Potter Cove (King George Island, South Shetlands) is a small fjord divided into the mouth and an inner part, separated by a transversal sill of about 30 m depth (Fig.1). The inner part has a muddy bottom, and is no deeper than 50 m. Glacier cliffs reach the cove in the north and east and the southern shore is a sandy beach. The mouth area is bordered by steep slopes in the north and by a broad intertidal platform in the Southeast (Klöser, 1994). The prevailing wind-driven currents determine a clock-wise circulation (Roese et al., 1993). In the whole research area, *Laternula elliptica* can be found by SCUBA divers from 3 m depth downwards.

Materials and methods

During one austral summer campaign, a large survey of the sublittoral benthos by SCUBA diving was performed. This included 12 underwater transversal transects (from 3 to 30 m depth), distributed in the whole research area (Fig.1). On this basis, photographic transects were undertaken together with natural sediment samplings (cores) for analysis of grain size and organic matter

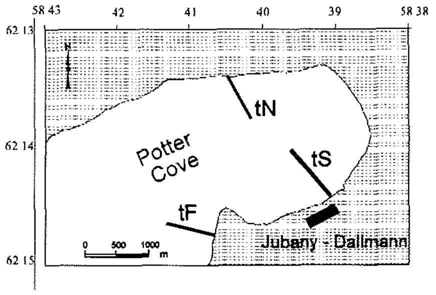

Figure 1: Potter Cove and location of transects tN, tS and tF.

content. Each photo transect consisted of 50-70 exposures taken on Kodak Ektachrome 64 slide film with a Nikonos V underwater camera (15 mm lens with a Nikonos SB-102 flash light), at a constant distance from the sea floor. The photo system was attached to a metal frame, equipped with a 0.25 m^2 quadrat, a metric scale, compass and depth gauge. The camera was triggered 3 to 10 times by a SCUBA diver each 3 m depth, at random. The present picture evaluation (not yet concluded) includes substrate type, number, size and orientation of siphons of *L. elliptica*, presence of other filter-feeder species and impact of grounding icebergs. Benthic diatoms are utilised as primary food source by this species and other benthic fauna (Ahn, 1993). Benthic diatoms biomass is also estimated visually on the pictures with a "covering index" ("C.I") (arbitrary scale from 0 to 5). The sediment samples were also taken by the divers using 20 cm^2 hand-held PVC corers (n=72) which sampled to a depth of 40 cm. On the same transects, cores were taken every 5 m depth. Sub-samples were collected from the uppermost 2 cm layer of each core for analysis of organic matter content (gravimetric). Sediment grain size was analysed using a Ro-Tap sieve shaker and a Sedigraph 5000D, after removing organic matter by soaking in 30% H_2O_2 and by rinsing with distilled water. Although the present study is not yet completed, some results are presented after the evaluation and comparison of data from 3 depths (5, 15 and 30 m) on 3 different transects (Fig.1), surveyed at 3 separated locations: 2 in the inner cove (from the northern shore, in front of the glacier cliffs: tN; from the southern shore, in front of Jubany Base: tS) and 1 located in the mouth of Potter Cove, from the south-eastern shore: tF.

Results

tN: (Fig.2) The highest density of *L. elliptica* was observed at 15 m depth (76 ind/m^2), where the sediment is very fine (62% silt-clay fractions), and also where the highest benthic diatoms "covering index" was measured (5). At 5 m depth the bottom consists mainly of unsorted moraine deposits (~80% pebble-sand fractions) and a lower density of bivalves was found (24 ind/m^2) together with a "poor" benthic diatoms "C.I" of 1.3. At 30 m depth (82% silt-clay fractions) few siphons were counted (4 ind/m^2). The benthic diatoms covering was not appreciable with our visual technique, but the highest organic matter (OM) content was measured (5,5%).

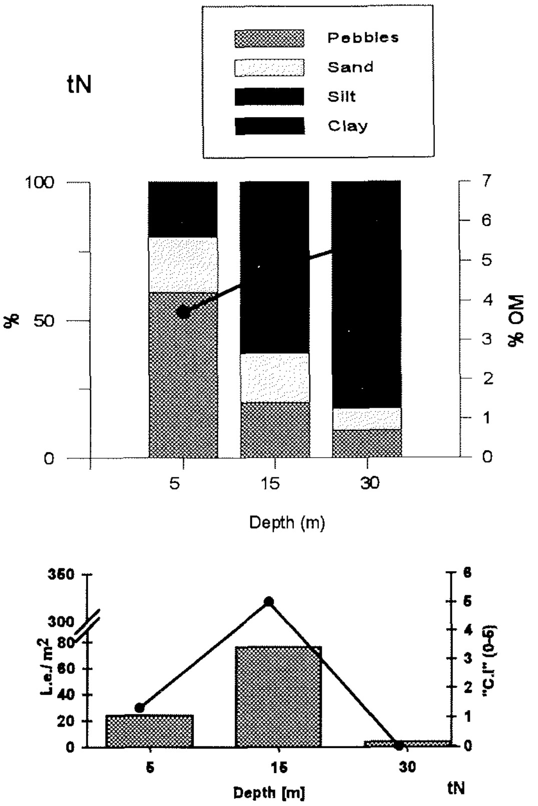

Figure 2: Transect tN. Upper: Grain size distribution (bars) and organic matter (filled circles and solid line) content of inhabited sediments. Down: Density of *Laternula elliptica* (bars) and "C.I." of benthic microalgae (filled points and solid line).

tS: (Fig.3) The highest bivalve density was measured at 5 m depth (346 ind/m^2) and corresponds to the highest value of the present study. The soft sediment consists of 95% sand, and a high 4.6 "C.I" was estimated. Here, no other sessile filter-feeders were observed in the photos. At 15 m depth the density of *L. elliptica* dropped down to 15 ind/m^2 and some sessile epifauna was present (mainly pennatulids). The sediments are fine (54% silt-clay fractions) and the measured "C.I" was 0.5. At 30 m depth the density dropped again to 5.3 ind/m^2 with a "C.I" of 0 . The sediments are also fine (65% silt-clay fractions) with the highest OM content of the transect (5,06%).

tF: (Fig.4) In the 3 sampling depths the bottom sediment consists mainly of sand (95% in 5 m to 46% in 30 m depth) and both at 5 m and 15 m the benthic diatoms "C.I" was very low (1 to 0) while no *L. elliptica* siphons were counted on the pictures. At 30 m depth (54% silt-clay fractions) the "C.I" was 0, the density

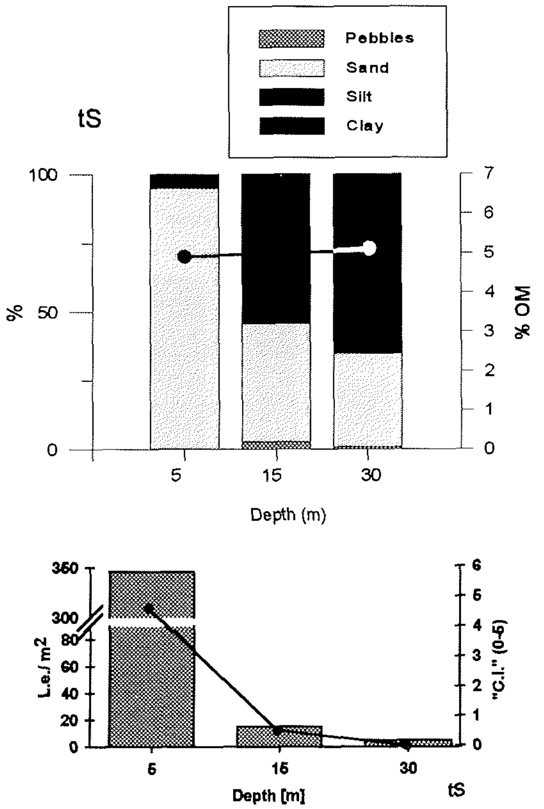

Figure 3: Transect tS. Upper: Grain size distribution (bars) and organic matter content of inhabited sediments (filled circles and solid lines). Down: Density of *Laternula elliptica* (bars) and "C.I." of benthic microalgae (filled points and solid line).

of the bivalve was 17.6 ind/m^2 and the highest organic matter (OM) content of the transect was measured (4,48%).

From the studied influencing factors, a significant positive correlation (Pearson's correlation coefficient) was found between the density of *L. elliptica* and the benthic diatoms biomass ("C.I")($r=0.791$, $p<0.005$, $n=12$), while no significant correlation was found between the grain size distributions of the inhabited sediments and the distribution and density of the bivalve.

Discussion

In tS and at 5 m depth, several biological and physical factors seem to be combined to favour the high occurrence of *L. elliptica*. Physical stress factors (ice impacts, drift ice accumulation, shock waves and tide turbulence) may act in 3 different ways : 1- pressing an impoverishment of the sessile epifauna (ascidians, sponges, pennatulids), 2- favouring the occurrence of the smaller individuals of the bivalve. These were found to have a higher success of reburial compared to that of bigger specimens, once they are unburied by

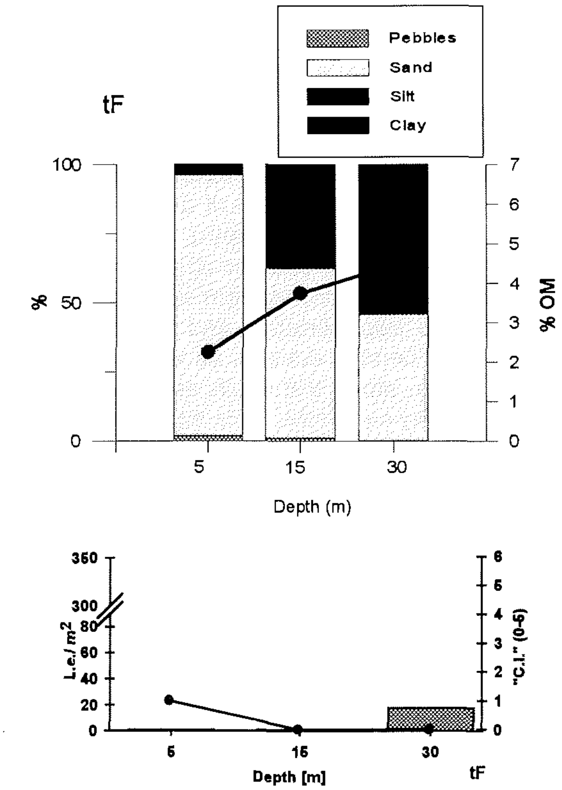

Figure 4: Transect tF. Upper: Grain size distribution (bars) and organic matter content of inhabited sediments (filled circles and solid lines), density of *Laternula elliptica* (bars) and "C.I." of benthic microalgae (filled points and solid line).

grounding icebergs, providing a better predator avoidance, 3- Forcing the resuspension of benthic diatoms, improving food availability and clearing the bottom for further colonisation of microalgae. The high organic matter output through biodeposition, and nutrients output through excretion by the dense population of *L. elliptica* may well enhance the continuous development of the benthic microalgae on the surrounding sediment. The role of allochtonous organic material provided by the discharge of Jubany Base and by the input of terrigenous particles from the creeks is an open question at present. This input is particularly high along the southern shore of the inner cove. Although the suspended sediments may lead to a strong shadowing of the water column, sufficient light would penetrate down to at lest 5 m depth for the development of the benthic diatoms. Light conditions may be unfavourable in deeper areas. Due to the clock-wise circulation pattern, this allochtonous material would not reach the northern shallow water assemblages of the inner part of the cove. In that place, a "clean blue water" incoming current allows a deeper penetration of light, thus providing good light conditions at 15 m depth, favouring a high "C.I"

(See density of *L.elliptica*, Fig.2). The disturbance factors are very strong in shallower depths (5 m). On this site, where frequent ice falls occur associated with shock waves, a lower density of animals was found. At 15 and 30 m depth, both in tN and tS, the soft substrates are colonised by a rich sessile fauna community, due to diminished turbulence. Dense patches of ascidians, pennatulids and sponges are observed. The outer parts of the Potter Cove area exhibit characteristics of an unprotected open shore, where iceberg impact is particularly severe along the slopes of Potter peninsula. This determines the almost exclusive occurrence of *L. elliptica* in locations with a lower probability of ice impact (30 m depth). This is supported by our observations, where no siphons were counted at 5 and 15 m depth in tF. The prevailing clock-wise current circulation pattern in Potter Cove (Roese et al., 1993) may well enhance the transportation and "export" of the allochtonous organic matter, resuspended benthic diatoms as well as spawned larvae, from the inner part of Potter Cove, along the south eastern shores, to the deeper bare plains of sand, where they can settle. This explains our observations at 30 m in tF. SCUBA divers reported very high densities of *L. elliptica* in the surroundings of Emm Rock (Klöser, 1994).

Future studies are required to improve our knowledge on the feeding ecology of this species. The seasonal variation of epontic algae, phytoplankton and benthic microalgal production strongly influence the life cycle of benthic filter-feeders dealing with variable food source availability. Data from sediment trap arrays, deployed at different heights from the bottom in Potter Cove, are still being processed. These will provide information for a better understanding of the bottom sediments and diatoms dynamics, and to evaluate the resuspension of microalgae as an important process providing organic material to benthic organisms in Antarctic coastal waters. In this sense, the benthic microalgal production may be the most important food source at least during a certain period of the year (Ahn et al., 1993).

References

Ahn, I.Y., Kang J.S. & Kang S-H. (1993). Primary food sources for shallow benthic fauna in Marian Cove, King George Island, during an austral summer. *Korean Journal of Polar Research*, Vol. 4(2): 67-72.

De Laca, T.E. & Lipps, J.H. (1976). Shallow-water marine associations, Antarctic Peninsula. *Antarct JUS* 11:12-20.

Döering, P.H., C.A. Oviatt & J.R. Kelly. (1986). The effects of the filter-feeding clam *Mercenaria mercenaria* on carbon cycling in experimental marine mesocosmos. *J. Mar Res.*, Vol. 44: 839-861.

Hardy, P. (1972). Biomass estimates from some shallow-water infaunal communities at Signy Island, South Orkney Island. *Br. Antarct. Surv. Bull.*, Vol. 31: 93-106.

Kautsky, N. & Evans (1987). Role of biodeposition by *Mytilus edulis* in the circulation of matter and nutrients in a Baltic coastal ecosystem. *Mar. Ecol. Prog. Ser.*, Vol. 38:201-212.

Klöser, H. (1994). Descripción básica de Caleta Potter y costas abiertas adyacentes. Contribución no.419: 5-6 del Instituto Antártico Argentino (IAA).

Ralph, R. & Maxwell, J.G.H. (1977). Growth of two Antarctic lamellibranchs: *Adamussium colbecki* and *Laternula elliptica*. *Mar. Biol.*, Vol 42:171-175.

Roese, M., Speroni, J., Drabble, M. & Pascucci, C.. Medición de corrientes en Caleta Potter, Antártida. Jornadas nacionales de Cs. del Mar, Puerto Madryn, 1993.

Vodopivez, C. & Curtosi, A. (1994). La utilización de *Laternula elliptica* y de *Nacella concinna* como indicadores biológicos de la presencia y distribución de metales pesados en la Isla 25 de Mayo (Antártida). Comunicación. Terceras Jornadas sobre Investigaciones Antárticas.

Vodopivez, C. & Curtosi, A. (1997). Resultados preliminares sobre el contenido de metales traza en bivalvos recolectados en los alrederores de la Estación Científica Jubany (Isla 25 de Mayo, Antártida). Contribución no.460 del Instituto Antártico Argentino (IAA).

Amphipods of Potter Cove: community composition, biology and growth

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Amphipods constitute an important element of Antarctic benthic communities, and they are one of the main food items of Antarctic fish (Thurston, 1970; Bregazzi 1972; Daniels, 1982; Agnew and Moore 1986; Gallardo, 1987; Klages and Gutt, 1990 a). In Antarctic coastal areas there are near 600 species of gammaridean amphipods, belonging to approximately 200 genera and 40 families (Klages and Gutt, 1990 b). The amphipod fauna of the West Antarctic region has been extensively studied, especially the community of the shallow sublittoral zone (Thurston, 1974 a, b). Studies on amphipod fauna of King George Island provide valuable information on systematic and ecological aspects of these populations (Rauschert 1988, 1989, 1990 a, b, 1991; Jazdzewski et al., 1991). However, little information is available on the biology, feeding and growth patterns of most amphipod species as well as on the spatial structure of the community.

Here we provide information on the composition and spatial distribution of the amphipod community in Potter Cove, summarizing the feeding characteristics of different species, the anatomy of their mouth parts, and showing allometric relationships among different body measures of several species that allow us describe the amphipods growth and estimate their biomass.

Sampling and methods

The samples were taken from the outer part of Potter cove which has rocky shores. Sampling was conducted monthly from February to June 1992 at three depths (5, 10 and 20 meters) by means of plastic traps (the traps have an area of 0.09 m^2) which were filled with stones and left on the bottom for a month to allow the colonization. The traps were replaced each month. Amphipods associated to macroalgae were sampled using plastic bags that wrapped the entire algae.

Specimens were fixed, identified, and number and biomass of each species estimated for each depth and surface unit.

Allometric equations represent the simplest relation between body dimensions and metabolic processes related to growth (for instance respiration, reproduction, mortality or predation rates) in several animals (Peters, 1993). These relations are useful tools for the identification of species and, moreover, to distinguish different life stages of a single species. If we measure two body dimensions in several individuals from a species, the expected behavior of dimensions is:

$$L_1 = a\,L_2^{\,b}$$

where L_1 and L_2 are two body dimensions, a is a constant, and b is the "allometric coefficient". Usually, b varies with sexual maturity and takes on different values for mature individuals of each sex.

For a subsample of each species obtained in Potter Cove, five body measures were recorded to study allometric relationships: the standard length (SL) from the rostrum to the base of the telson (because in preserved samples the telson can be lost), the length of the head (Lh), the height of the fourth somite (Hp), and the height (Hc) and the length (Lc) of the fourth coxae (Fig. 1).

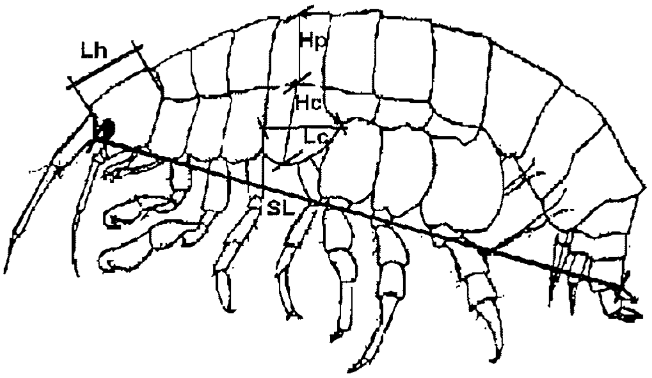

Figure 1. Body measures taken for allometric studies: SL, standard length; Lh, head length; Hp, height of the fourth pereionite; Hc, height of the fourth coxae; Lc, length of the fourth coxae.

Results

We found 19 species belonging to 9 families (Tab. 1). The more abundant species are *Bovallia gigantea* (Eusiridae), *Pariphimedia integricauda* (Iphimediidae), *Schraderia gracilis* (Eusiridae), and *Valletia coheres* (Lysianassidae). *Gondogeneia antarctica* (Eusiridae), an important herbivore in antarctic shelfs (Momo, 1995), is abundant as well as the scavenging and detritivore amphipods *Cheirimedon dentimanus* (Lysianassidae) and *Orchomenella acanthura* (Lysianassidae).

Table 1. List of species found in Potter Cove.

- IPHIMEDIIDAE
    - *Pariphimedia integricauda Chevreux, 1906*
- AMPHILOCHIDAE
    - *Gitanopsis antarctica Chevreux, 1912*
- CALLIOPIDAE
    - *Oradarea rossi* Thurston, 1974
    - *Oradarea walkeri* Shoemaker, 1930
    - *Oradarea ocellata* Thurston, 1974
- DEXAMINIDAE
    - *Paradexamine fissicauda* Chevreux, 1906
- EUSIRIDAE
    - *Bovallia gigantea* Pfeffer, 1888
    - *Eurymera monticulosa* Pfeffer, 1888
    - *Gondogeneia antarctica* (Chevreux, 1906)
    - *Pontogeneiella brevicornis* (Chevreux, 1906)
    - *Pontogeneiella longicornis* (Chevreux, 1906)
    - *Prostebbingia sp* (Chevreux, 1906)
    - *Schraderia gracilis var gracilis* (Pfeffer, 1888)
    - *Schraderia gracilis var calceolata* (Pfeffer, 1888)
- ISCHYROCERIDAE
    - *Jassa wandeli Chevreux, 1906*

LYSIANASSIDAE
    Cheirimedon dentimanus Chevreux, 1905
    Orchromenella acanthura (Schellenberg, 1931)
    Valettia coheres Stebbing, 1888
STENOTHOIDAE
    Metopoides walkeri Chevreux, 1906
THAUMATELSONIDAE
    Thaumatelson walkeri Chilton, 1912

The spatial distribution is not uniform neither in numbers nor in biomass (Fig. 2). Considering the number of individuals, we can observe a dominance of *Bovallia gigantea* at 5 and 10 meters in association with some of their prey species: *Eurymera monticulosa* (Eusiridae) and *Pariphimedia integricauda*. Both are herbivores with an ability also to feed on detritus. In deeper traps (20 m) *Valletia coheres*, *Metopoides walkeri* (Stenothoidae), and *Schraderia gracilis* are dominant. When we consider the biomass, *Bovallia gigantea*, *Eurymera monticulosa* and *Pariphimedia integricauda* are always dominant because of their larger body size.

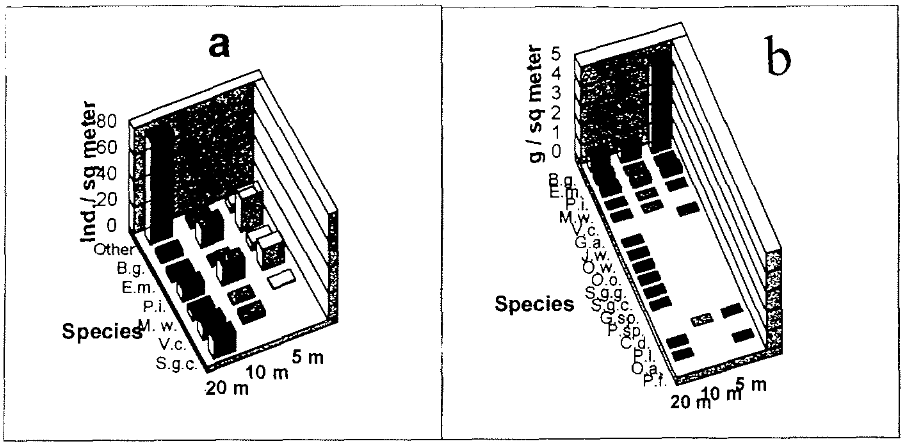

Figure 2: Spatial distribution of amphipods at different depths: a) number; b) biomass. B.g.: *Bovallia gigantea*, E.m.: *Eurymera monticulosa*, P.i.: *Pariphimedia integricauda*, M.w.: *Metopoides walkeri*, V.c.: *Valettia coheres*, S.g.g.: *Schraderia gracilis var gracilis*, S.g.c.: *Schraderia gracilis var calceolata*, G.a.: *Gondogeneia antarctica*, J.w.: *Jassa wandeli*, O.w.: *Oradarea walkeri*, O.o.: *Oradarea ocellata*, G.sp.: *Gitanopsis antarctica*, P.sp.: *Prostebbingia sp.*, C.d.: *Cheirimedon dentimanus*, P.l.: *Pontogeneiella longicornis*, O.a.: *Orchromenella acanthura*, P.f.: *Paradexamine fissicauda.*

There is an association between feeding characteristics of amphipods and the anatomy of their mouth parts, especially the mandibles. *Eurymera monticulosa*, which may cut and triturate algae and detritus, has a mandible with a well developed molar and a cutting incisor (Fig. 3, a). By contrast, *Pariphimedia integricauda* has a mandible more adapted to a scavening diet (Fig. 3 b), although this species is normally considered to be herbivore. *Paradexamine fissicauda* (Dexaminidae) is detritivore and scavenger and has a mandible with a big molar and a multidentate incisor, supported by a lacinia mobilis (fig. 3, c). These little organisms eat any kind of detritus available. *Jassa wandeli* (Ischyroceridae) is a facultative detritivore-carnivore and has large gnathopods and a mandible adapted for a generalist diet (Fig. 3, d); this species is located at 20 m and deeper, where the availability of detritus is highest (Momo, 1995) and there is macroalgae of the genera *Desmarestia* and *Himantothallus* which give to amphipods protection and food (Quartino, 1994).

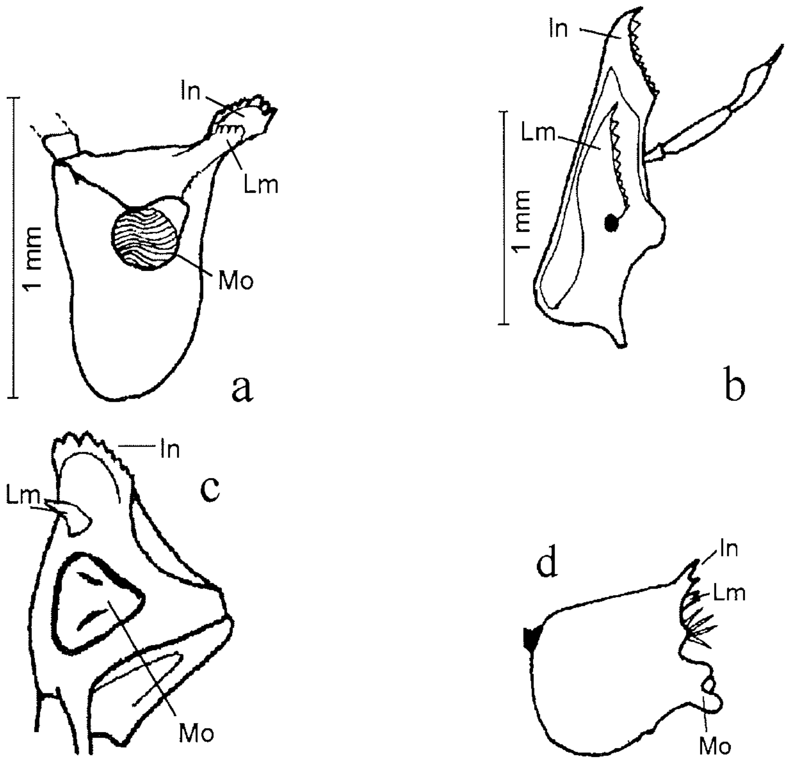

Fig. 3. Mouth parts of some amphipods of Potter Cove. a) *Eurymera monticulosa*; b) *Pariphimedia integricauda*; c) *Paradexamine fissicauda*; d) *Jassa wandeli*. In, incisor; Mo, molar; Lm, lacinia mobilis. All draws correspond to left mandibles except c that is a right one.

Other feeding habits observed in the species collected are the following: *Bovallia gigantea* is a carnivore, *Gondogeneia antarctica* is a herbivore, *Cheirimedon dentimanus* is a detritivore, and *Gitanopsis antarctica* (Amphilochidae) is a detritivore and a scavenger.

For the investigated species, the relationships between the standard length and each of the other body measures are roughly linear (Fig. 4) and there are no differences between the allometric coefficients of younger and mature adults. In certain species, with very round shapes, the correlations were not significant. A summary of the relationships found is given in Table 2.

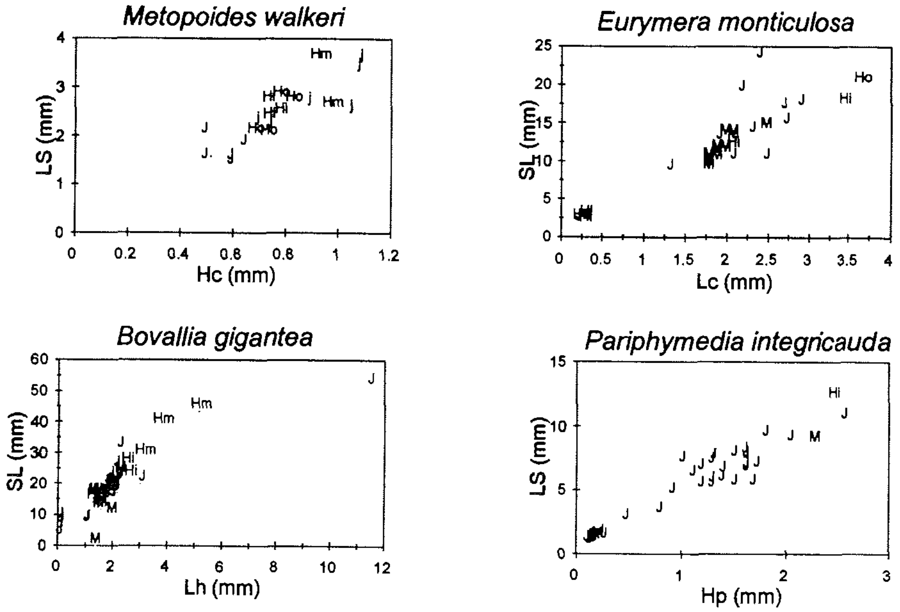

Fig. 4. Examples of allometric relationships in amphipods from Potter Cove. J, youger; Hi, immature female; Hm, mature female; Ho, female with eggs; M, male.

Table 2. Linear correlations between standard body length (SL) and other body measures. NS not significant, * P < 0.10, ** P < 0.05.

Species	Hp	Lc	Hc	Lh
Bovallia gigantea	*	*	*	*
Eurymera monticulosa	*	NS	*	**
Gondogeneia antarctica	*	*	NS	*
Metopoides walkeri	NS	*	NS	*
Oradarea ocellata	*	*	*	*
Pariphimedia integricauda	*	*	*	*
Schraderia gracilis var. gracilis	*	*	*	*
Valettia coheres	*	*	*	*

Conclusions: The amphipod community studied in the outer part of Potter Cove is only a little fraction of the total biota recorded (see for instance Rauschert, 1991 or Jazdzewski et al., 1991); this is probably due to the peculiar characteristics of this area. However, we can observe a vertical zonation and an association between the species and their food sources (prey or detritus).

The morphology of mandibles provides useful information about the dietary preferences of species but this information needs to be checked against gut contents and behavioral studies such as the works of Klages and Gutt (1990 a, b).

The growth of some species may be described by allometric equations; this means that body measures can be used to describe the growth and to estimate the standard length of individuals, which is very useful for food chain studies, as it will help to estimate food uptake to gut content material of amphipod predators.

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References

Agnew D. J. and Moore P. G. (1986). The feeding ecology of two littoral amphipods (Crustacea) *Echinogammarus pirloti* (Sexton & Spooner) and *E. obtusatus* (Dahl). Journal of Experimental Marine Biology and Ecolology, 103:203-216.

Bregazzi P. K. (1972). Life cycles and seasonal movements of *Cheirimedon femoratus* (Pfeffer) and *Tryphosella kergueleni* (Miers) (Crustacea: Amphipoda). British Antarctic Survey Bulletin, 30: 1-34.

Daniels R. A. (1982). Feeding ecology of some fishes of the Antractic Peninsula. Fish. Bull., 80: 575-588.

Gallardo V. A. (1987). The sublittoral macrofaunal benthos of the Antarcic Shelf. Environ Internat., 13: 71-81.

Jazdzewski K., De Broyer C., Teodorczyk W. and Konopacka A. (1991). Survey and distributional patterns of the amphipod fauna of Almiralty Bay, King George Island, South Shetland Islands. Polish Polar Research, 12(3): 461-472.

Klages M. and Gutt J. (1990a). Observations on the feedig behaviour of the Antarctic Gammarid *Eusirus perdentatus* Chevreux, 1912 (Crustacea: Amphipoda) in aquaria. Polar Biology, 10: 359-364.

Klages M. and Gutt J. (1990b). Comparative studies on the feeding behaviour of high Antarctic amphipods (Crustacea) in laboratory. Polar Biology, 11: 73-79.

Momo F. (1995). Ciclo de vida y distribuci6n espacial de *Gondogeneia antarctica* Chevreux (Crustacea; Amphipoda). Doctoral Thesis, Buenos Aires University.

Peters R. H. (1993). The ecological implications of body size. Cambridge Studies in Ecology. Cambridge University press.329 pp.

Quartino, L. 1994. Algas marinas bentónicas de caleta Potter. Dirección Nacional del Antártico, Contribuciones n° 419: 42-46.

Rauschert M. (1988). Gammaridea (Crustacea, Amphipoda) aus der Küstenregion von King George (Süd-Shetland-Inseln). Mitt. zool. Mus., Berlin, 64: 299-310.

Rauschert M. (1989). *Atylopsis* fragilis n. sp. (Crustacea, Amphipoda, Gammaridae, Eusiridae) aus dem Sublittoral von King George (Süd-Shetland-Inseln). Mitt. zool. Mus., Berlin, 65: 127-138.

Rauschert M. (1990a). New amphipods from the sublittoral of King George Island: Faunistic contribution to ecological investigations. Geod. geophys Veröff. Reihe 1, n° 15-16; Proc. Symp. Ant. Res., 1-2: 447-458.

Rauschert M. (1990b). Neue Stenothoidae (Crustacea, Amphipoda, Gammaridea) aus dem Sublitoral von King George (Süd-Shetland-Inseln). Mitt. zool. Mus., Berlin, 66: 3-39.

Rauschert M. (1991). Ergebnisse der faunistischen Arbeiten im Benthal von King George Island (Südshetlandinseln, Antarktis). Berichte zur Polarforschung, 76: 1-75.

Thurston M. H. (1970). Growth in *Bovallia gigantea* Pfeffer (Crustacea: Amphipoda). In Antarctic Ecology (M. W. Holdgate, ed). Academic Press, London: 269-278.

Thurston M. H. (1974a) The Crustacea Amphipoda of Signy Island, South Orkney Islands. British Antarctic Survey Scientific Report, 71: 1-133.

Thurston M. H. (1974b) Crustacea Amphipoda from Graham and the Falkland Islands Dependencies Survey. British Antarctic Survey Scientific Report, 85: 1-89.

Species composition and seasonal population structure of *Oithona similis* (Copepoda, Cyclopoida) in the Potter Cove (Jubany, King George Island, Antarctica)

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Introduction

Seasonal population structure and vertical distribution of cyclopoid and small calanoid copepods in coastal (e.g. Tanimura et al., 1986; Foster, 1987; Tucker and Burton, 1990) and open waters (e.g. Fransz, 1988; Hopkins and Torres, 1988; Hopkins et al., 1993; Schnack-Schiel and Mizdalski, 1994) of the Antarctics have been investigated before. Most of the investigations were carried out during austral summer (Kaczmaruk, 1983; Chojnacki and Weglenska, 1984; Gonzales et al., 1994, Metz, 1995). Only a few studies provide data from the austral autumn (Kurbjeweit, 1993; Metz, 1996). However, this is the first study to present data from a year-round survey in a shallow coastal environment of the maritime Antarctic, with samples taken at regular intervals at a permanent station. Moreover, copepod species composition and population structure of planktonic copepods in the Potter Cove (King George Island, Antarctica) have never been investigated before. The aim of this study was to gain information about their life cycles.

Material and Methods

The zooplankton (< 5 mm) of the Potter Cove has been studied from October 1995 to June 1996 and October 1996 to October 1997. Samples were taken at regular intervals at a permanent station in the inner cove. Vertical hauls were taken from the bottom to the surface (max. depth 38 meters) at station 1 with an Apstein net (aperture 0.125 m^2, meshsize 55 μm) and fixed in 4% formalin (final concentration). In the laboratory, species and copepodite stages were identified and counted from the whole sample (Heron, 1977; Nishida, 1985). The filtered volume (fv) was calculated from net aperture and sampling depth as follows:

a) $fv\ [m^3] = 0.04[m^2] * \pi *$ sampling depth [m] .

Results

Environment and food conditions

Environmental parameters have been measured by Irene Schloss and Gustavo Ferreyra (for details see Schloss et al., this volume). The hydrographic conditions in the Potter Cove were mainly influenced by strong westerly and easterly winds. The average wind speed ranged between 9 and 11 m/s from October 1995 to December 1996.

Due to wind induced vertical mixing, the water column was homogeneous in most parts of the year. Stratification was only observed in spring and summer due to heavy fresh water run off from the glacier and rivers discharging into the Cove. The water temperatures ranged between +1.4 °C (March 1996) and -1.9 °C (August/September 1996). The Chlorophyll *a* concentration was low throughout the investigation period. In the growing season it did not exceed 4 µg/l, with an average of 1 µg/l. Data of the year 1997 have not been available as yet.

Species composition

Only 8 calanoid and 4 cyclopoid species were found in the Potter Cove. Most of them occured sporadically and in abundances lower than 3 Ind./m³, namely, *Calanoides acutus*, *Calanus propinquus*, *Metridia gerlachei*, *Rhincalanus gigas*, *Microcalanus pygmaeus*, *Stephos longipes*, *Racovitzanus* sp., *Oithona frigida* and *Pseudocyclopina eddatreyae nov. spec.* About 95% of the copepodids belonged to the species *Oithona similis*, *Oncaea curvata* and *Ctenocalanus citer*. *O. similis* was the overall most abundant species and occured in sufficient abundances to be discussed in this study.

The cyclopoid species *Oithona similis* and *Oncaea curvata* contributed more than 80% to the copepods sampled during the investigation period (Fig. 1). *Ctenocalanus citer* was the most abundant calanoid species. The total abundances of *O. similis* ranged between <10 Ind./m³ and 350 Ind./m³. With abundances less than 10 Ind./m^3 *O. curvata* could hardly be detected for most of the year (Fig. 2). In 1996 and 1997 the abundance raised to maximum values in May 1996 (190 Ind./m^3) and July 1997 (44 Ind./m^3), respectively. Also, *C. citer* was most abundant in May and June but the values did not exceed 33 Ind./m³ (Fig. 2).

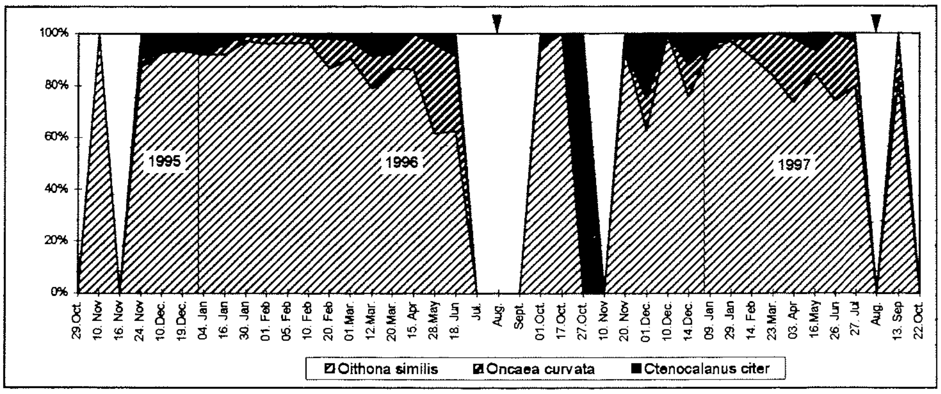

Fig. 1. Relative abundance [%] of the most abundant species *Oithona similis*, *Oncaea curvata and Ctenocalanus citer* at station 1 from October 1995 to June 1996 and October 1996 to October 1997. The arrowheads indicate a lack of samples.

Abundance and population structure of Oithona similis

The total abundance of *Oithona similis* was generally low in October and November (< 30 Ind./m^3) and raised to a maximum of 130 Ind./m^3 in January and February (Fig. 2). In March the abundances were comparable to those in November/December but raised again until they reached a second maximum of 350 Ind./m^3 in May 1996 and 140 Ind./m³ in July 1997, respectively.

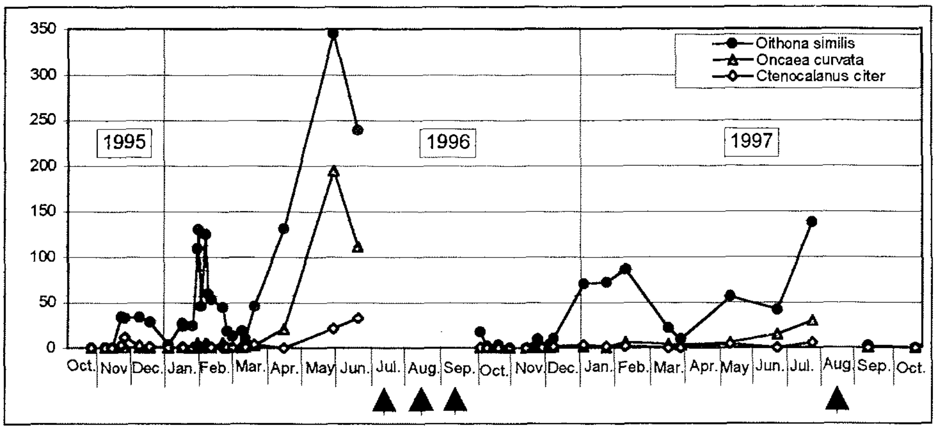

Fig. 2. Total abundance [Ind./m^3] of *Oithona similis*, *Oncaea curvata* and *Ctenocalanus citer* from October 1995 to June 1996 and October 1996 to October 1997 at station 1 in the Potter Cove.The arrowheads indicate a lack of samples.

The stage distribution of *Oithona similis* is characterized by a change from older copepodids in spring and summer to younger stages (< CIV) in autumn and winter (Fig. 3. From the beginning of spring until the end of summer the population was dominated by adults and CV stages with > 80% (Fig. 3). At this time developmental stages < CIV were also found but their contribution to the population was less than 15%. From March their relative abundance raised continuously and reached maximum values of > 80% in June, predominated by copepodite stage IV (> 40%). Females with eggs first appeared midst of November and could be found at all seasons (Fig. 5). Conclusively, it can be noted that the first maximum in the total abundance of *Oithona similis* mainly contains adults, while the second maximum is dominated by early copepodite stages (I-III).

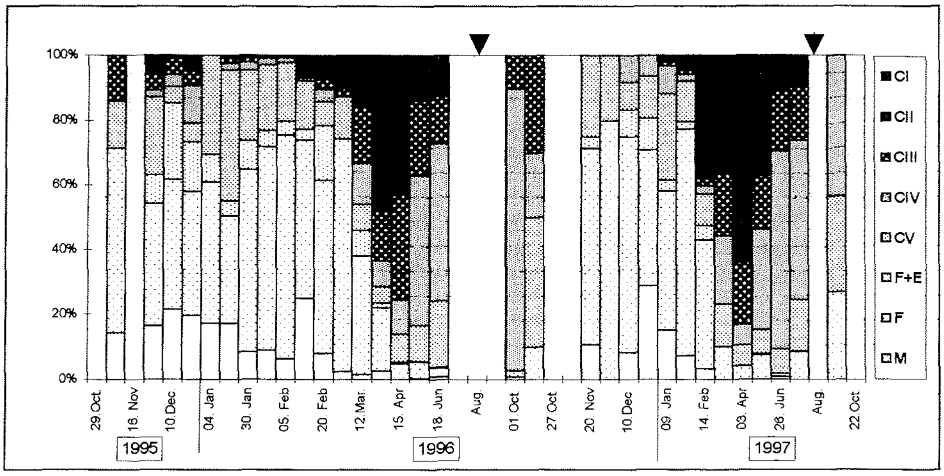

Fig. 3. Relative abundance [%] of the developmental stages of *Oithona similis* at station 1 from October 1995 to June 1996 and October 1996 to October 1997. The arrowheads indicate lack of samples.

Discussion

The total abundance of copepods found in the Potter Cove in summer is comparable to those found by Chojnacki and Weglenska (1984) in the Admirality Bay (King George Island) and Zmijewska (1987) in the Bransfield Strait. Although, *Oithona similis* was the most abundant species, their total abundance did not exceed 140 Ind./m^3 in summer. This is probably due to different hydrographical conditions around the South Shetland Islands. The water masses can be divided into two zones with rather distinct hydrographical conditions, the Antarctic Zone (AAZ) and the Continental Zone (CZ) with a boundary called the Continental Water Boundary (CWB) running along the continental slope north-west of the South Shetlands (Whitworth, 1980). The AAZ waters are distinctly warmer and less saline than the CZ waters (Jazdzewski et al., 1982). The Bransfield Strait is situated in the CZ zone and influenced by water masses from the Bellingshausen Sea in their western and northern parts, while the eastern part is influenced by a branch of the Weddell Sea coming in from North and going down South along the Antarctic Peninsula. Jazdzewski et al. (1982) showed that the mean abundances of zooplankton in the top 100 m layer of the AAZ zone (mean number 3067 Ind./m^3) are by an order of magnitude higher than those found in the CZ zone (mean number 159 Ind./m^3). Moreover, *Calanoides acutus* and *Calanus propinquus* were more abundant in AZZ waters than in CZ waters, while *Oncaea curvata* was rather absent in AZZ waters but a common feature in CZ waters. *O. similis* was the predominant copepod species in both water masses but less abundant in the CZ zone. The species composition and abundance found in the Potter Cove may therefore be described as typical for Bransfield Strait waters. The predominance of small copepod species may also be an indication of the local hydrography, marked by high turbidity, freshwater inflow and sediment resuspension. Williams et al. (1994) postulate for the European shelf seas that "...tidally mixed near shore environments support zooplankton communities dominated by smaller copepods...", while seasonal thermally stratified waters are dominated by larger herbivorous copepod species.

The general and almost simultaneous increase of the total abundance in the three most abundant species, *Oithona similis*, *Oncaea curvata* and *Ctenocalanus citer* in autumn and winter is supposed to be not just influenced by the increase of reproduction in summer but also by a probable change in the hydrography of the adjacent waters. Mackintosh (1934) observed a seasonal shift in the abundance of plankton in the top 100 m layer from Cape Horn to the Antarctic Peninsula. He concluded "...it seems possible that there is normally a rich plankton in the central part of the Drake Strait which spreads further south towards the end of the summer". It is to be mentioned that his conclusions are based on a comparison of results from different years and months and may therefore be a matter of coincidence.

Comparing the seasonal population structure in the Potter Cove with the results of Metz (1996) from the Bellingshausen Sea there seems to be a delay in the first appearance of CI and CII stages. While in the Bellingshausen Sea CI and CII dominated the population structure in summer with 60 - 70%, these stages contributed less than 30% to the total population in the Potter Cove. In autumn an opposite situation could be found, with a relative abundance of copepodite stages I and II higher in the Potter Cove than in the Bellingshausen Sea. The population structure of *Oithona similis* in the Bellingshausen Sea found by Metz (1996) shows that the stage composition of this species does not just vary seasonally but also spatially, especially in spring. While early copepodite stages (I and II) were rather rare in one area, they dominated the population in another, area nearby. This may lead to the conclusion that *O. similis* is able to react quite rapidly to changes in environmental parameters. Due to the presence of males during the whole year there is no restriction of reproduction from this point of view.

The dominance of adults in January and February of *Oithona similis* was also found by Chojnacki and Weglensla (1984) which leads to the conclusion that reproduction takes mainly place in these months but also on a lower level during autumn and winter (see a*bundance and population structure of Oithona similis)*. All copepodite stages of *O. similis* were found in winter, dominated by CIII and CIV. In agreement with this study, Tanimura et al. (1997) also found all copepodite stages of *Oithona similis* in July under the sea ice near "Syowa Station" (East Ongul Island, Antarctica). Part of copepodite stages CV appearing in spring are supposed to be from the last year generation but due to the fact that CIII and CIV copepodids are dominating the winter population but could hardly be found in November the majority of CV may have also molted from overwintering CIII/CIV during the winter. In contradiction to the herbivorous copepod species which have to time their spawning period to ensure a sufficient food supply for the developing generation (Voronina, 1972; Davis, 1976), *O. similis* may deal with the advantage to be able to feed also on detritus, like stated for *Oncaea curvata* (Metz, 1996), which may be available during the whole year.

Fransz (1988) suggested that the strategy of the antarctic small-sized copepod species is to maintain a "..stable population structure with a wide range of (st)age distribution, based on a more or less continuous reproduction". The results of this study may verify this suggestion at least for *Oithona similis.*

References

Chojnacki, J., Weglenska, T (1984) Periodicity of composition, abundance, and vertical distribution of summer zooplankton (1977/1978) in Ezcurra Inlet, Admirality Bay (King George Island, South Shetland). J. Plankt. Res. 6: 997-1017.

Davis, C.C. (1976) Overwintering strategies of common planktic copepods in some north Norway fjords and sounds. Astarte 9: 37-42.

Foster, B.A. (1987) Comparison and abundance of zooplankton under the spring sea ice of McMurdo Sound, Antarctica. Polar Biol. 8: 41-48.

Fransz, H.G. (1988) Vernal abundance, structure and development of epipelagic copepod populations of the eastern Weddell Sea (Antarctica). Polar Biol. 9: 107- 114.

Gonzales, H.E., Kurbjeweit, F.K., Bathmann, U.V. (1994) Occurence of cyclopoids and faecal material in Halley Bay region, Anarctica, during January-February 1991. Polar Biol. 14: 331-342.

Heron, G.A. (1977) Twenty-six species of Oncaeidae (Copepoda: Cyclopoida) from the southwest Pacific-Antarctic area. Antarct. Res. Ser. 26: 37-96.

Hopkins, T.L., Torres, J.J. (1988) The zooplankton community in vicinity of the ice edge, western Weddell Sea, March 1986. Polar. Biol. 9: 79-87.

Hopkins, T.L., , Lancraft, T.M., Torres, J.J. and Donnelly, J. (1993) Community structure and trophic ecology of zooplankton in the Scotia Sea marginal ice zone in winter (1988). Deep Sea Res. 40: 81-105.

Jazdzewsky, K., Kittel, W., Lotocki, K. (1982) Zooplankton studies in the southern Drake Passage and in the Bransfield Strait during the austral summer (BIOMASS-FIBEX, February - March 1981). Pol. Polar Res. 3 (3-4): 203-242.

Kaczmaruk, B. Z. (1983) Occurence and distribution of the Antarctic copepods along the ice shelves in the Weddell Sea in summer 1979/80. Meeresforschung 30: 25-41.

Kurbjeweit, F. (1993) Reproduktion und Lebenszyklen dominanter Copepodenarten aus dem Weddellmeer, Antarktis. Ber. Polarforsch. 129: 1-238.

Mackintosh, N. A. (1934) Distribution of the macroplankton in the Atlantik Sector of the Antarctic. Discovery Rep., 9: 65-160.

Metz, C. (1995) Seasonal variation in the distribution and abundance of *Oithona* and *Oncaea* species (Copepoda, Crustacea) in the southeastern Weddell Sea, Antarctica. Polar Biol. 15: 187-194.

Metz, C. (1996) Lebensstrategien dominanter antarktischer Oithonidae (Cyclopoida, Copepoda) und Oncaeidae (Poecilostomatoida, Copepoda) im Bellingshausenmeer. Diss. Christian-Albrecht-Universität, Kiel. 117.

Nishida, S. (1985) Taxonomy and distribution of the family Oithonidae (Copepoda, Cyclopoida) in the Pacific and Indian Oceans. Bull. Ocean. Res. Inst., Univ. Tokyo 20: 167 pp.

Schloss, I., Ferreyra, G., Klöser, H. (see this volume)

Schnack-Schiel, S. B., Mizdalski, E. (1994) Seasonal variations in distribution and population structure of *Microcalanus pygmaeus* and *Ctenocalanus citer* (Copepoda: Calanoida) in the eastern Weddell Sea, Antarctica. Mar. Biol. 119: 357-366.

Tanimura, A., Fukuchi, M., Hoshiai, T. (1986) Seasonal change in the abundance of zooplankton and species composition of copepods in the ice-covered sea near Syowa Station, Antarctica. Mem. Nat. Inst. Polar Res., issue 40: 212-220.

Tanimura, A., Hoshino, K., Nonaka, Y., Miyamoto, Y., Hatori, H. (1997) Verical distribution of *Oithona similis* and *Oncaea curvata* (Cyclopoida, Copepoda) under sea ice near Syowa Station in the Antarctic winter. Proc. NIPR Symp. Polar. Biol. 10: 134-144.

Tucker, M.J., Burton, H. R. (1990) Seasonal and spatial variations in the zooplankton community of an eastern Antarctic coastal location. Polar. Biol. 10: 571-579.

Voronina, M.N. (1972) The spatial structure of interzonal copepod populations in the Southern Ocean. Mar. Biol. 15: 336-343.

Wiliams, R., Conway, D.V.P., Hunt, H.G. (1994) The role of copepods in the planktonic ecosystems of mixed and stratified waters of the European shelf seas. Hydrobiologia 292/293: 521-530.

Witworth, T. III (1980) Zonation and geostrophic flow of the Antarctic Circumpolar Current at Drake Passage. Deep Sea Res., 27 A: 497-507.

Zmijewska, M.I. (1987) Horizontal and vertical distribution of copepoda in the southern part of the Drake Passage and in the Bransfield Strait (BIOMASS-SIBEX 1983/1984). Pol. Polar Res., 8 (4): 381-390.

ECOLOGY OF DEMERSAL FISH SPECIES FROM POTTER COVE

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Species composition and their distribution

The fish species inhabiting Potter Cove are coastal notothenioids of the South Shetlands Islands area (Fig. 1, A). They are demersal shallow water fish (< 120 m deep) which spend all or part of their life cycles in inshore waters, although some of them also occur in the offshore fraction of the shelf, at depths down to a range of 200-550 m (Barrera-Oro 1996). The most frequent fish species found are the nototheniids *Notothenia coriiceps* (previously referred to as *N. neglecta*), *N. rossii, Lepidonotothen nudifrons, Trematomus newnesi, Gobionotothen gibberifrons* and *T. bernacchii,* the harpagiferid *Harpagifer antarcticus,* and in less frequency the bathydraconid *Parachaenichthys charcoti* and the channichthyid *Chaenocephalus aceratus*. The sampling gear used to catch these fish have been trammel/gill nets, hook and lines and traps (Barrera-Oro and Casaux 1990, Casaux et al. 1990, Barrera-Oro and Marschoff 1991). Trammel/gill nets have shown to be the best gear, their advantages are capture of a higher quantity of fish in a short time, negligible by-catch of benthic organisms and easy operation from rubber boats. Pelagic nets aimed to sample pelagic stages of fish (larvae, postlarvae, early juvenile) and pelagic fish (i.e. myctophids, *Pleuragramma antarcticum*) which may occur in the cove temporally, have not been used. *Harpagifer antarcticus* (from tide-pools), *N. coriiceps* (from 5 m depth) and *N. rossii* (from 10 m depth) are the more neritic species, *G. gibberifrons, L. nudifrons* and *T. newnesi* occur more frequently from 30-45 m depth, whereas *T. bernacchii, P. charcoti* and *C. aceratus* are caught from a depth range of 70-90 m downwards. *Notothenia rossii* occurs in the cove in the juvenile stage exclusively, after which they migrate offshore to join and spawn with the adult part of the population (Casaux et al. 1990, Barrera-Oro and Casaux 1992). *Gobionotothen gibberifrons* displays an evident length stratification as a function of depth; mainly juvenile and part of the adult population coexist in inshore shallow waters (Casaux et al. 1990, Barrera-Oro 1989, Kulesz 1994). *Notothenia coriiceps* is the dominant fish in the area of study, both in number and biomass (Barrera-Oro and Marschoff 1991). Our data on its depth distribution from Potter Cove and data from South Georgia suggest that this species remains nearshore during its whole life cycle (Casaux et al. 1990, Burchett et al. 1983). However, other studies indicate that at least around Elephant Island, South Shetland Islands *N. coriiceps* migrates to deeper waters to spawn (Everson 1970, Hureau 1970, Kock 1989).

It is known that areas with high macroalgae diversity show greater fish abundance (Zukowski 1980, Duhamel 1982, Burchett 1983a). In Potter Cove, this was confirmed by diving observations and also by ecosounder registrations in the inner part of the cove, bordered by a glacier, where the bottom is covered by glacial sediments and is devoid of algae, and where fish were absent or scarcely found (mostly *L. nudifrons*) (Fig. 1, B). The external part is the entrance to the cove and has a rocky bottom covered mainly with

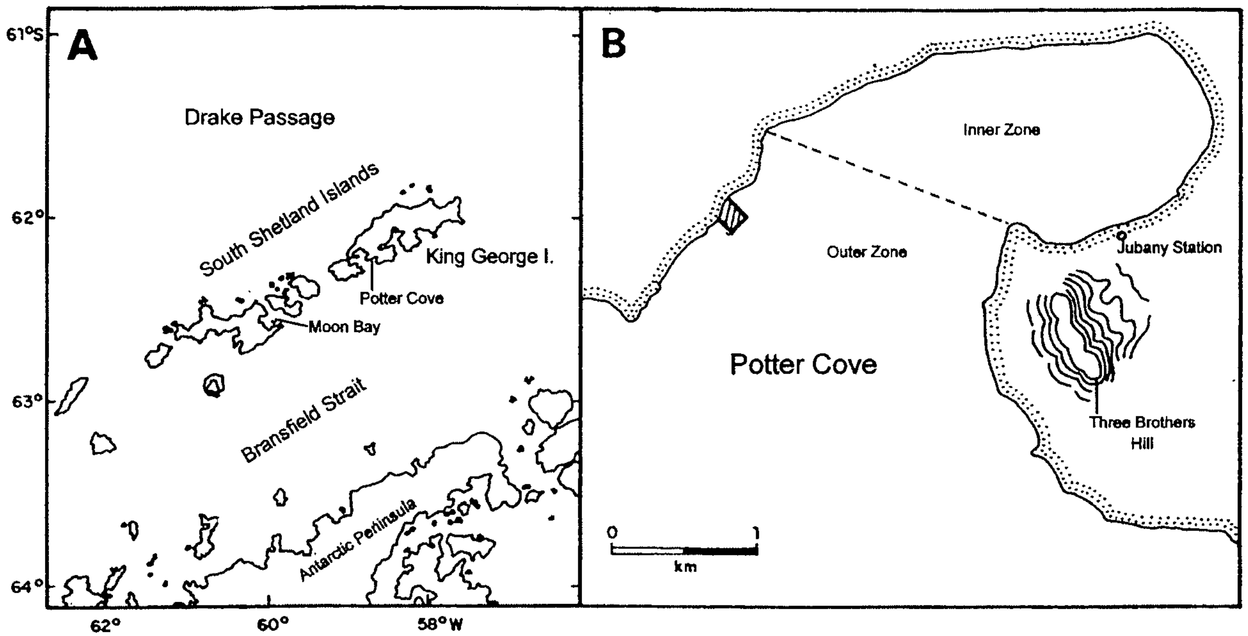

Fig. 1 . The location of Potter Cove and Moon Bay at the South Shetland Islands (A) and the sampling area (square) at Potter Cove (B).

red and brown algae. Algal densities increase gradually from the inner to the external zone, where the fauna associated with algal beds is rich and diverse, including polychaetes, gammarid amphipods, isopods, chitons, bivalves, corals, ophiuroids, asteroids, echinoids, tunicates, ascidians and fish (Barrera-Oro and Casaux 1990, Casaux et al. 1990). Thus, in nearshore communities macroalgal environments offer to fish a diversity of prey and shelter from potential predators such as penguins and mammals.

Feeding ecology, populational aspects and role in the food web

Several aspects of the trophic role of the fish species of Potter Cove have been considered (Barrera-Oro 1996). Among the feeding types, three categories were segregated: benthic feeders, which feed mainly on benthic organisms including infauna, epifauna and algae, are *H. antarcticus*, *L. nudifrons*, *N. coriiceps* and *G. gibberifrons*. Benthophagous, non-generalist species, which also feed sporadically in the water column, are *T. bernacchii*, *T. newnesi*, juvenile *N. rossii*, *P. charcoti* and *C. aceratus*. Plankton feeders, which prey almost exclusively in the water column, are early juvenile stages of many notothenioids (e. g. *C. aceratus*).

The feeding behaviours include ambush feeding by *H. antarcticus*, *L. nudifrons*, *G. gibberifrons*, *N. coriiceps*, *N. rossii* and *T. bernacchii*, slurp by *G. gibberifrons*, grazing by *N. coriiceps*, *N. rossii*, *G. gibberifrons* and *T. bernacchii* and water column feeding by *N. rossii*, *T. bernacchii*, *T. newnesi*, *P. charcoti* and *C. aceratus* (Barrera-Oro 1996). Some species use alternatively or combine more than one strategy to feed on a wider spectrum of organisms.

Grazing is an important feeding strategy and although it has been thought that the utilisation of macroalgae by Antarctic fish in terms of energy is poor, fish can assimilate between 20% (Montgomery and Gerking 1980) and 90% (Horn 1989) of the algae ingested. Depending on the method of diet analysis algae appear to be a secondary food (coefficient Q, Hureau 1970) for *N. coriiceps*, *G. gibberifrons* and *N. rossii* or even the main food item if the frequency of occurrence method is used (Barrera-Oro and Casaux 1990, Casaux et al. 1990). However, it has been discussed whether algae are eaten on purpose by fish, or whether they are accidentally ingested in association with other prey (Showers et al. 1977, Moreno and Zamorano 1980, Daniels 1982, Burchett 1983a). Our studies on this matter carried out at Potter Cove arrive at conclusions that differ from those published in the literature in the following points: i) high frequency of occurrence of algae in the fish stomachs, ii) independent ingestion of algae (i.e., not only in connection with amphipods) and iii) selection of algae in conjunction with the capacity to digest them. This supports the hypothesis that the algae are actively selected and consumed deliberately by fish (Barrera-Oro and Casaux 1990, Casaux et al. 1990, Iken 1995, Iken et al. 1997). Therefore, at least some Antarctic fish species (e.g. *N. coriiceps*, *G. gibberifrons*, *N. rossii*, *T. newnesi*) should be considered omnivorous.

A study of feeding selectivity in *N. coriiceps* at Potter Cove was carried out by comparing the abundance and biomass of benthic organisms from 0-40 m with their occurrence in the diet of 142 fish (Barrera-Oro and Casaux 1990). Ivlev's index (1961) indicated that the food items positively selected by the fish included sessile, mobile and infaunal organisms such as sedentary polychaetes, the isopod *Glyptonotus antarcticus*, the gammarid amphipod *Paradexamine* sp., the bivalve *Dacrydyum* sp., the gastropods *Margarella antarctica* and *Eatoniella* sp., and algae. We suggest that several of the important factors associated with selectivity are: prey size, mobility, type of fixing to substratum, activity, digestibility and camouflage. The biomass of the benthic community in the sampling area was low, presumably due to the effects of anchor ice. Despite being pelagic, krill (*Euphausia superba*) was by far the main food of *N. coriiceps*.

The diet may change with the ontogeny of the fish species and also with the seasonal availability and geographical origin of their prey. As the fish grow larger, their trophic spectrum may increase because the size spectrum of the prey they are able to capture becomes wider. Prey size is reflected by a clearly defined framework of target species, the proportions of which change primarily as a function of the predator's own size (Barrera-Oro and Tomo 1987). For example, in Potter Cove, *N. coriiceps* of increasing size shows a greater tendency to piscivory and preys less on gammarid amphipods. Demersal juvenile *N. rossii* prey mainly on benthic organisms, whereas adult specimens have a planktonic diet (Casaux et al. 1990).

Seasonal variations in the diets of fish were observed at Potter Cove (Casaux et al. 1990). Gammarid amphipods are the main prey during most of the year, but during the summer months, fish take advantage of the occurrence of krill and other pelagic organisms (hyperiid amphipods) in the cove, to feed on them intensively (Barrera-Oro and Casaux 1990). Krill enter inshore shallow waters mainly in summer and their accessibility to demersal fish can be explained in two ways: 1) the vertical distribution of krill reaches the bottom, where they are eaten by opportunistic feeders (Barrera-Oro and Casaux 1990, Everson 1977, Kock 1985, Gutt and Siegel, 1994); 2) demersal fish migrate to the mid-water zone to feed on pelagic forms (Barrera-Oro and Casaux 1990, Everson 1977, Freytag 1980, Daniels 1982, Duhamel and Hureau 1985, Kock 1985). It is possible that a combination of both mechanisms takes place in this area.

In Potter Cove, due to the importance of gammarid amphipods as prey, food competition among fish species would seem to be high (Casaux et al. 1990). However, among generalist species with a benthophagous feeding pattern (e.g., *G. gibberifrons*, *N. coriiceps* and juvenile *N. rossii*) interspecific competition is mitigated by resource partitioning. We found that the different species of gammarids in the area are the prey of different fish species, as for example, amphipods living amongst the algae for *N. coriiceps* and epibenthic gammarids for *G. gibberifrons*. *Harpagifer antarcticus* is a specialized feeder which hunts mainly mobile epibenthic amphipods in also specialized habitats such as rubble bottoms. The effectiveness of these strategies to mitigate food competition was demonstrated in an analysis of the diet overlap carried out among fish species of this study, in Potter Cove and in another locality of the South Shetland Islands, Elephant Island (Barrera-Oro 1996). The results from the two fish assemblages show that there was low overlap among diets (21-29%). Similar conclusions were extracted from other studies, in the adjacent areas of the South Orkney Islands (Targett 1981) and the Antarctic Peninsula (Daniels 1982).

Information on fish activity in relation to day light indicates that many demersal ambush feeder species such as *N. coriiceps*, *G. gibberifrons* and *N. rossii* are more active during the dark, presumably due to the greater night activity of their prey (Richardson 1975, Moreno and Zamorano 1980, Burchett 1983b). Observation by divers confirm that shallow-water fish hide during the day. However, during our two 48-h sampling sequences carried out at Potter Cove using trammel nets (Casaux et al. 1990), *N. coriiceps* was caught mainly during the day time. As the trammel net is a passive sampling device (contrary, for example, to trawl nets), catches depend on fish activity (Barrera-Oro and Marschoff 1991). Diving observations could be unreliable to evaluate this type of behaviour, since the fish in the presence of the diver would seek refuge, which could be erroneously interpreted as a passive behaviour (Casaux et al. 1990). In conclusion, the information on the dial feeding activity of Antarctic demersal fish is still inconsistent.

The size (15-55 cm) and age (3-13 years) ranges of *N. coriiceps* indicate that demersal juvenile and adult specimens co-exist in Potter Cove. This agrees with data from coastal nearby localities such as Admiralty Bay, King George Island (Linkowski and Zukowski 1980). At Potter Cove the youngest mature male and female *N .coriiceps* were 6 years old, at 320 and 345 mm, respectively. The presence of all five stages in the gonad cycle (Everson 1977) suggests that spawning occurs in coastal waters of the island. The mature stage (IV) appeared in both sexes from February to May, therefore spawning probably occurs during these months, in which a high number of larger specimens predominated in the catches and again decreased in number after spawning (Casaux et al. 1990). This appears to indicate that mature specimens migrate to the sampling area to spawn, as was also described by Burchett (1983b) for shallow waters off South Georgia Island. Different findings have been reported by other authors for other areas (discussed above).

The ranges of age (4-12 years) and size (14-38 cm) confirm that mainly juveniles and younger adults of *G. gibberifrons* occur in Potter Cove. Likewise, the analysis of the gonads showed that mature adult specimens (stage IV) were absent from Potter Cove, indicating that they might migrate to deeper water (Casaux et al. 1990).

As expected, only demersal juvenile individuals (age 3-7 years, size 18-44 cm) of *N. rossii* were caught at Potter Cove (Barrera-Oro and Casaux, 1992).

The main pathway of energy flow through demersal fish in the food web of an Antarctic inshore shallow water zone such as Potter Cove is shown in Fig. 2. It seems that demersal fish play a significant role in the energy flow because they are the main predators of benthos feeding virtually on all the organisms present below their own trophic level from algae to fish, and also feed on zooplankton in the water column (Barrera-Oro 1996). On the other hand, demersal fish are common prey of birds (particularly, the Antarctic shag *Phalacrocorax bransfieldensis*) and seals (discussed in this volume, section 4). Through these high predators, the energy is transferred to the land in form of fish remains, pellets and regurgitations (birds) and faeces (birds and seals). The role of strict pelagic fish species that may occur in the cove (i.e. myctophids, Pleuragramma antarcticum) or pelagic stages of fish (larvae, postlarvae, early juvenile) is not comparable to that of demersal fish, since the former fish feed in the water column exclusively on zooplankton, and there is no or little (e.g. faeces, dead animals) energy transfer between them and the benthos community (Barrera-Oro 1996). The role of krill in inshore shallow waters is by far less important for fish or for the benthos

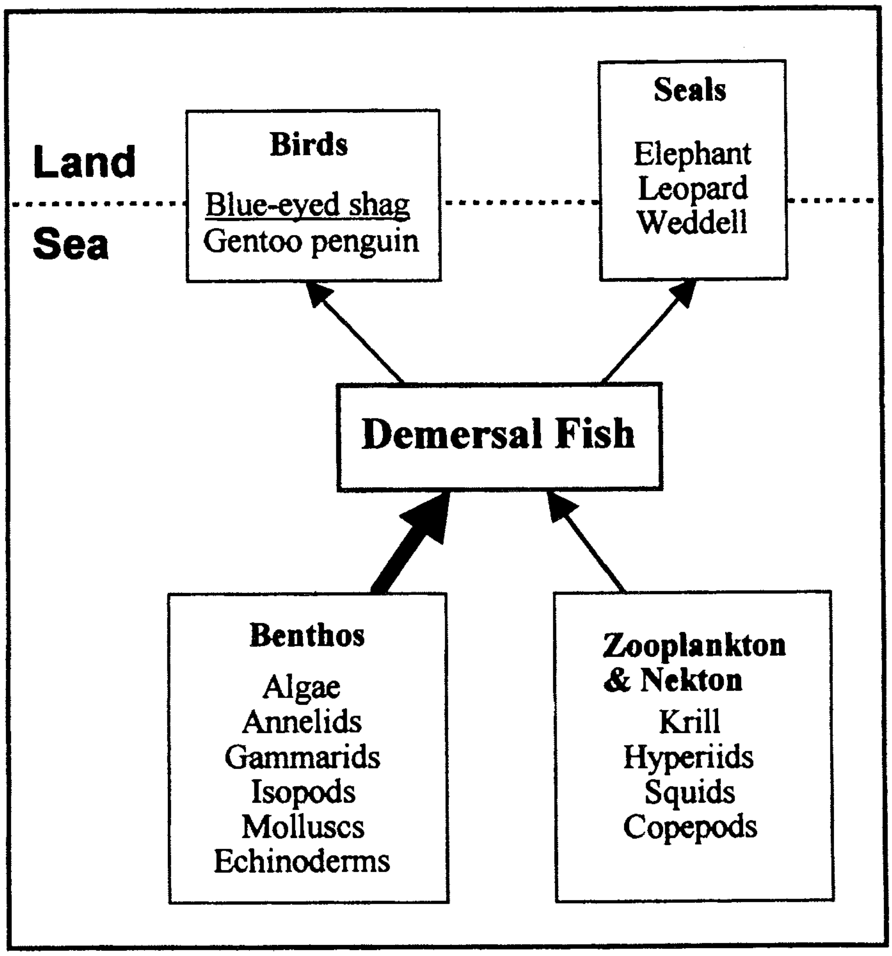

Fig. 2 . Scheme showing the position of demersal fish in the food web of an inshore shallow water community such as Potter Cove.

community than in the offshore portion of the Antarctic ecosystem, probably because the occurrence of krill as a food resource in neritic areas is restricted mainly to the summer season. Likewise, in offshore waters, the energy flow trough demersal fish is much less important than inshore. Fish depend less on benthic organisms and feed more intensively on krill and other pelagic forms such as salps, hyperiid amphipods and pelagic fish.

Size, age and growth

Size, age and growth are essential parameters in the assessment of fish population dynamics necessary for adequate fisheries management. This subject is of particular importance in the Antarctic marine ecosystem, considering the present low status of many exploited fish stocks. Our studies on this field in Potter Cove concentrate on age determination, validation methods and growth of species commercially important (*N. rossii, G. gibberifrons*) or of potential commercial value (*N. coriiceps*) in the Southern Ocean .

The demersal fish species of Potter Cove are of small (9.5-24 cm, *H. antarcticus, L. nudifrons, T. newnesi*), intermediate (34-42 cm, *T. bernacchi, P. charcoti*) and large (44-75 cm, *N. rossii, G. gibberifrons, N. coriiceps, C. aceratus*) size (TL).

In Antarctica, there are no particular differences in growth between the inshore and offshore fraction of coastal notothenioid species, not even in the size that krill/non-krill feeders can reach, but abundance and total biomass of offshore krill-dependent species are higher than of inshore demersal species in general. Commercially exploited species such as *N. rossii* (adults) and the mackerel ice fish *Champsocephalus gunnari* among others, constitute examples of this rule (Barrera-Oro 1996). In the shallow water communities of the South Shetland Islands, including Potter Cove, *N. coriiceps* is at present by far, in terms of abundance and biomass, the most successful species.

Scales and whole otoliths were used for age estimation of juvenile *N. rossii* specimens collected between 1983 and 1988 (Barrera-Oro and Casaux 1992). We validated the age determination for age groups 3-5 years, by identifying peaks in the length frequency analysis (Petersen method). Also, the detailed comparison of both types of material is a method used to help validation, which resulted in 97 % of agreement. The examination of otolith cross sections of chosen specimens confirmed in all the cases the age readings obtained from the second whole sagittal otolith. Although the commonly accepted 1 July was used as the birth date of the fish for age calculations, data indicate that 1 October is closer to the biological birth date, since this species hatches in Spring. The length-age range of the fish was 18-44 cm and 3-7 years respectively, which fits well with the known length-age distribution of juvenile specimens of the species in the fjord. A comparison between observed and back-calculated mean length of age group 3 (24.6 and 25 cm respectively) indicated that not only the larger fish but the full size range of this age group was represented in our samples. Mean length data at age for Potter Cove fish are similar to the ones reported for fish from Admiralty Bay, King George I. (Linkowski and Zukowski 1980), but are lower than those of fish caught off Elephant Island (Freytag 1980, Kock 1988). These differences could be attributed to a size-specific as opposed to age-specific offshore migration: the larger sized fish of an age group are thought to migrate offshore first, this resulting in an overestimation of the mean length value. However, considering also that Elephant Island is the northernmost island of the South Shetland Islands, the difference between the results from both areas could be explained by geographical or populational variations. It is also possible that differences could be attributed to different criteria used in the interpretation of the growth rings. The use of whole otoliths for age estimation of juvenile *N. rossii* proved to be a reliable method with a precision of one year, but this might not be an appropriate technique for adult specimens.

For age determination, *G. gibberifrons* samples consisted of small and medium sized fish (14.8-35 cm) caught from February to May 1986. Otolith and scale readings were compared, resulting in some cases of one year more in scales (Barrera-Oro 1989). This could arise from the difficulty in differentiating between false and annual checks in scales. Age determination by otolith cross sections proved to be the most reliable method. Fish in the range of 4-12 years old were found in the cove. Mean length data at age for fish of the South Shetland Islands area were compared with published values for other regions. This confirmed that fish inhabiting waters around the South Shetland Islands are smaller than those in the same age group around South Georgia. Colder water at higher latitudes seems to be responsible for such a decrease in growth (Barrera-Oro 1989).

Among all available age validation procedures tag-recapture experiments give the most reliable information. Validation studies by this technique had not been published so far in the Antarctic (Barrera-Oro and Casaux 1996a).

Of 409 *N. coriiceps* specimens tagged and released at Potter Cove, in successive years from 1989 to 1992, 9 were recaptured at the same site after periods of 11-21 months (Barrera-Oro and Casaux 1996a). A comparison was carried out between checks found in scales removed before and after the period of release. In scales of those specimens recovered after 11-13 months, one extra annulus was laid down. The same analysis in one individual recovered after 21 months resulted in 2 extra closely spaced sclerite zones, which corresponded with an elapse of two winter seasons. The comparative analysis between scales taken at recapture and otolith cross sections of the same individual allowed a simultaneous counting of the annuli with good agreement. These results validate the principle of annual deposition of the annulus in scales and otoliths of *N. coriiceps*. The analysis of scales regenerated during the whole release period provided additional information, indicating that these observations are of value in validation procedures.

Monitoring

Besides krill and in small scale squid (recently), finfish is at present the only living resource commercially exploited in the Antarctica. A matter of research of our Ichthyology Project is the impact of the offshore fishery on inshore fish in the South Shetland Islands area.

Commercial fishing in the South Shetland Islands/Antarctic Peninsula started in 1978/79. Since then, a total of 87139 t of finfish were caught until 1989/90 (Kock 1992). Heavy fishing was carried out off the northern coasts of the northernmost island, Elephant Island, in the period 1977-1980, but catches from other islands and from the north of the Antarctic Peninsula have been also reported (Anonymous 1990). *Champsocephalus gunnari* and *N. rossii* were the main targeted species, constituting 47% and 22% of the total catch, whereas *G. gibberifrons* was to some extent also taken in a directed fishery and as by-catch (4151 t) (Kock 1992). As a consequence of the fishing operations in the Atlantic sector of the Southern Ocean the stocks of many species were seriously depleted. For example, until 1992, the stock size of *N. rossii* at South Georgia was estimated to be less than 5% of the original stock size in 1969 (Kock 1992).

Young specimens of *N. rossii* and *G. gibberifrons* inhabit nearshore waters; major changes in the offshore (reproductive) stock may be reflected in the inshore populations through recruitment processes. We have studied this phenomenon at two sites of the South Shetland Islands, Potter Cove, and Moon Bay, Livingston Island, with samples obtained by trammel nets (Barrera-Oro and Marschoff 1991). Trawling has been scarcely used due to the lack of appropriate bottoms. Trammel/gill nets is a passive sampling device, catches depend solely on fish activity. Therefore, changes in population size are expected to be reflected by proportional changes in catches. Over a period of eight years of fish monitoring at Potter Cove (1983-1990) a sharp decline in the abundance of juvenile *N. rossii* and *G. gibberifrons* was found, whereas the stock of *N. coriiceps*, a species with similar ecological habits in the fjords which is not fished commercially, remained stable (Barrera-Oro and Marschoff 1991). A similar phenomenon was observed at Moon Bay and neighbouring sites, by comparison of historical data taken since 1965 (Bellisio 1967, Moreno and Bahamonde 1975, Linkowski et al. 1983) with our data recorded in 1989 in the region.

These findings, obtained by monitoring of fish species through long time periods, are supported by our studies on the diet of the Antarctic shag *P. bransfieldensis* in the same area (see this volume, section 4): while the fish species identified in stomach contents and pellets agreed qualitatively and in relative numbers with those regularly sampled with trammel-nets, *N. rossii* and *G. gibberifrons* are not or are scarcely represented (Casaux and Barrera-Oro 1993, Barrera-Oro and Casaux 1996b, Casaux et al. 1997, Coria et al. 1995, Favero et al. 1998). Moreover, at the onset of the last decade in waters around the South Orkney Islands, a fishing ground still affected by the commercial fishery, *N. rossii* was a frequent prey of *P. bransfieldensis* (see Shaw 1984), but this fish species was not represented in our analogous study in that area (Casaux et al. 1997).

The decline of juvenile *N. rossii* and *G. gibberifrons* observed at Potter Cove, Moon Bay and other neighbouring localities of the South Shetland Islands was explained as caused by a reduction in recruitment due to the severe depletion suffered by the reproductive stock during the historical fishing operations in the area (Barrera-Oro and Marschoff 1991).

Monitoring of pre-recruit fish by means of trammel nets was previously applied by Duhamel (1990) in the Morbihan Gulf, Kerguelen Islands. He reported a reduction in juvenile *N. rossii* inshore catches as being caused by the depletion of the offshore reproductive stock due to the operation of the commercial fishery. Further monitoring showed a continuous recovery of the juvenile stock from 1984 to 1988, after the closure of the fishery (Duhamel 1990). Such recovery process has still not been observed in Potter Cove in any of the two species studied (Barrera-Oro and Marschoff 1991).

Notothenia coriiceps has proliferated markedly in the last 12-15 years in the South Shetland Islands area both in number and biomass, parallely with the decrease in the *N. rossii* (Kock 1986, Skora 1988) and *G. gibberifrons* populations (Barrera-Oro and Marschoff 1991), already mentioned. It is probable that during this period *N. coriiceps* encountered progressively less interspecific competition and consequently expanded its trophic and habitat niches.

References

Anonymous, 1990. Commission for the Conservation of Antarctic Marine Living Resources. *Statistical Bulletin,* Vol. I-II.

Barrera-Oro, E.R. & Tomo, A.P. 1987. Feeding and ecology of *Notothenia larseni,* Lönnberg. In *Antarctic Aquatic Biology,* ed. S. El Sayed. *Biomass Scientific Series* No.7, 99-106.

Barrera-Oro, E.R. 1989. Age determination of *Notothenia gibberifrons* from the South Shetland Islands, Antarctic Peninsula Subarea (Subarea 48.1).*CCAMLR Selected Scientific Papers,* 1988, 2, 143-160.

Barrera-Oro, E.R. & Casaux, R.J. 1990. Feeding selectivity in *Notothenia neglecta,* Nybelin, from Potter Cove, South Shetland Islands, Antarctica. *Antarctic Science,* 2 (3), 207-213.

Barrera-Oro, E.R. & Marschoff, E.R. 1991. A declining trend in the abundance of *Notothenia rossii marmorata* and *Notothenia gibberifrons* observed in fjords in two sites in the South Shetland Islands. *CCAMLR Selected Scientific Papers,* 1990, 263-274.

Barrera-Oro, E.R. & Casaux, R.J. 1992. Age estimation for juvenile *Notothenia rossii* from Potter Cove, South Shetland Islands. *Antarctic Science,* 4 (2), 131-136.

Barrera-Oro, E.R. 1996. Ecology of inshore demersal Antarctic Fish (Notothenioidei) from the South Shetland Islands. Doctoral Thesis, University of Bremen, June 1996.

Barrera-Oro, E.R. and Casaux, R.J. 1996a. Validation of age determination in *Notothenia coriiceps* by means of a tag/recapture experiment at Potter Cove, South Shetland Islands. *Archive of Fishery and Marine Research,* 43 (3), 205-216.

Barrera-Oro, E.R. & Casaux, R.J. 1996b. Fish as diet of the blue-eyed shag, *Phalacrocorax atriceps bransfieldensis* at Half-Moon Island, South Shetland Islands. *Cybium,* 20 (1), 37-45.

Bellisio, N. B. 1967. Peces Antárticos del sector Argentino (Parte 4), *Parachaenichthys charcoti, P. georgianus* y *Harpagifer bispinis antarcticus* de Bahía Luna. *Publicación del Servicio de Hidrografía Naval,* 904, 1-57.

Burchett, M.S. 1983a. Food, feeding and behaviour of *Notothenia rossii marmorata* nearshore at South Georgia. *British Antarctic Survey Bulletin,* 61, 45-51.

Burchett, M.S. 1983b. Abundance of the nearshore fish population at South Georgia (Antarctica) sampled by trammel net. *British Antarctic Survey Bulletin,* 61, 39-43.

Burchett, M.S., Sayers, P.J., North, A.W. & White, M.G. 1983. Some biological aspects of the nearshore fish population at South Georgia. *British Antarctic Survey Bulletin,* 59, 63-74.

Casaux, R.J., Mazzotta, A.S. & Barrera-Oro, E.R. 1990. Seasonal aspects of the biology and diet of nearshore nototheniid fish at Potter Cove, South Shetland Islands, Antarctica. *Polar Biology,* 11 (1), 63-72.

Casaux, R.J. & Barrera-Oro, E.R. 1993. The diet of the blue-eyed shag, *Phalacrocorax atriceps bransfieldensis* feeding in the Bransfield Strait. *Antarctic Science,* 5 (4), 335-338.

Casaux, R.J., Coria, N. & Barrera-Oro, E.R. 1997. Fish in the diet of the Antarctic shag *Phalacrocorax bransfieldensis* at Laurie Island, South Orkney Islands. *Polar Biology,* 18, 219-222.

Casaux, R.J., Favero, M., Coria, N. & Silva, P. 1997. Diet of the imperial cormorant *Phalacrocorax atriceps bransfieldensis*: comparison of pellets and stomach contents. *Marine Ornithology,* 25, xx-xx.

Coria, N., Casaux, R., Favero, M. & Silva, P. 1995. Analysis of the stomach content of the blue-eyed shag *Phalacrocorax atriceps bransfieldensis* at Nelson Island, South Shetland Islands. *Polar Biology,* 15, 349-352.

Daniels, R.A. 1982. Feeding ecology of some fishes of the Antarctic Peninsula. *Fishery Bulletin,* 80, 575-588.

Duhamel, G. 1982. Biology and population dynamics of *Notothenia rossii* from the Kerguelen Islands (Indian sector of Southern Ocean). *Polar Biology*, 1, 141-151.

Duhamel, G. & Hureau J.C. 1985. The role of zooplankton in the diets of certain Sub-Antarctic marine fish. In *Antarctic nutrient Cycles and Food Webs*, ed. W.R. Siegfried, P.R. Condy & R.M. Laws, pp. 421-429. Berlin: Springer Verlag.

Duhamel, G. 1990. Supplementary data on exploited stocks in Division 58.5.1 (Kerguelen). *CCAMLR Selected Scientific Papers,* 1989, 147-161.

Everson, I. 1970. Reproduction in *Notothenia neglecta* Nybelin. *British Antarctic Survey Bulletin,* 23, 81-92.

Everson, I. 1977. The living resources of the Southern Ocean. GLO/SO/77/1 Rome, *FAO/UN Development Programme*, 156 pp.

Favero, M., Casaux, R.J., Silva, P., Barrera-Oro, E.R. & Coria, N. 1998. The diet of the Antarctic shag during summer at Nelson Island, Antarctica. *The Condor*, 100, 112-118.

Freytag, G. 1980. Length, age and growth of *Notothenia rossii marmorata* Fischer 1885 in the West Antarctic waters. *Archiv für Fischereiwissenschaft*, 30, 39-66.

Gutt, J. & Siegel, V. 1994. Benthopelagic aggregations of krill *(Euphausia superba)* on the deeper shelf of the Weddell Sea (Antarctic). *Deep Sea Research,* 141, 169-178.

Horn, M.H. 1989. Biology of marine herbivorous fishes. *Oceanography and Marine Biology, Annual Review*, 27, 167-272.

Hureau, J.C. 1970. Biologie comparée de quelques Poissons antarctiques (Nototheniidae). *Bulletin de l' Institut Océanographique, Monaco,* 68 (1391), 244 pp.

Iken, K. 1995. Trophische Beziehungen zwischen Makroalgen und Herbivoren in der Potter Cove (King George-Insel, Antarktis). Doctoral Thesis, Universität Bremen, 1995.

Iken, K., Barrera-Oro, E.R., Quartino, M.L., Casaux, R.J. and Brey, T. 1997. Grazing by the Antarctic fish *Notothenia coriiceps*: evidence for selective feeding on macroalgae. *Antarctic Science*, 9 (4), 386-391.

Kock, K.H. 1985. Krill consumption by Antarctic notothenioid fish. In *Antarctic nutrient Cycles and Food Webs*, ed. W.R. Siegfried, P.R. Condy & R.M. Laws, pp. 437-444. Berlin: Springer Verlag.

Kock, K.H. 1986. The state of exploited Antarctic fish stocks in the Scotia Arc Region during SIBEX (1983-1985). *Archiv für Fischereiwissenschaft*, 37, 129-186.

Kock, K.H. 1988. Preliminary results of a bottom trawl survey around Elephant Islands in october and december 1987. (*WG-FSA*- 88-31) *Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1988,* Part II: 185-200.

Kock, K.H. 1989. Reproduction in fish around Elephant Island. *Archiv für Fischereiwissenschaft,* 39 (1), 171-210.

Kock, K.H. 1992. Antarctic fish and fisheries. Cambridge, New York: Cambridge University Press. 359 pp.

Kulesz, J. 1994. Seasonal biology of *Notothenia gibberifrons, N. rossii* and *Trematomus newnesi,* as well as respiration of young fish from Admiralty Bay (King George, South Shetland Islands). *Polskie Archiwum Hydrobiologii*, 41, 79-102.

Linkowski, T.B. & Zukowski, C. 1980. Observation on the growth of *Notothenia coriiceps neglecta* Nybelin and *Notothenia rossii marmorata* Fischer in Admiralty Bay (King George Island, South Shetland Islands). *Polish Polar Research,* 1, 155-162.

Linkowski, T.B., Presler, P. & Zukowski, C. 1983. Food habits of nototheniid fishes (Nototheniidae) in Admiralty Bay (King George Island, South Shetland Islands). *Polish Polar Research*, 4, 79-95.

Montgomery, W.L. & Gerking, S.D. 1980. Marine macroalgae as food for fishes: an evaluation of potential food quality. *Environmental Biology of Fishes,* 5 (2), 143-153.

Moreno, C.A. & Bahamonde, N. 1975. Nichos alimentarios y competencia por el alimento entre *Notothenia coriiceps neglecta* Nybelin y *Notothenia rossii marmorata* Fischer en Shetland del Sur, Antártica. *Serie Científica del Instituto Antártico Chileno,* 3, 45-62.

Moreno, C.A. & Zamorano, J.H. 1980. Selección de los alimentos en *Notothenia coriiceps neglecta* del cinturón de macroalgas de Bahía South, Antártica. *Serie Científica del Instituto Antártico Chileno,* 25/26, 33-44.

Richardson, M.G. 1975. The dietary composition of some Antarctic fish. *British Antarctic Survey Bulletin,* 41, 113-120.

Shaw, P. 1984. Factors affecting the breeding performance of the Antarctic Blue-eyed Shag (*Phalacrocorax atriceps bransfieldensis*). Ph.D thesis, University of Durham.

Showers, W.J., Daniels, R.A. & Laine, D. 1977. Marine biology at Palmer Station, 1975 austral winter. *Antarctic Journal of the United States*, 12, 22-25.

Skora, K.E. 1988. Benthic fishes of the Elephant Island shelf (Biomass III, October-November 1986 and February 1987). *Polish Polar Research,* 9, 385-398.

Targett, T.E. 1981. Trophic ecology and structure of coastal Antarctic fish communities. *Marine Ecology Progress Series,* 4, 243-263.

Zukowski, C. 1980. Catches of fishes of the genus Notothenia and Trematomus at Admiralty Bay (King George Island, South Shetland Islands) in the winter-spring season, 1977. *Polish Polar Research*, 1, 163-167.

Southern elephant seal migration and Antarctic sea ice

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The colony of southern elephant seals (*Mirounga leonina*) at „Stranger Point" on King George Island (62°14'S – 58°40'W) is the only breeding colony in the Antarctic. It consists of about 650 females distributed in several harems of up to 80 cows, each harem usually dominated by a single bull. Elephant seals are the largest of the pinnipeds in the southern hemisphere, pregnant females weighing up to 800 kg and males up to 4000 kg. The females reach the breeding sites between September and October and give birth to a single pup of 40 to 50 kg body weight. The lactation period lasts on average 23 days, and after weaning the pups remain ashore for a further 5 to 8 weeks during which they complete their moult. After mating the adult females go to sea and at about ten weeks the weaners. The pelagic phase of the females is interrupted by the 2 to 3 week haul-out for moulting during January and February.

Although the time ashore for both lactation and moulting is only 10 to 15 % of a seal's annual cycle, the greatest changes in weight and body condition occur during this time. All animals – except sucked pups – fast during the breeding and moulting period, and nearly all energy requirements have to be derived from the blubber and metabolism. For further details of the bioenergetics of southern elephant seals see Carlini et al. (this issue). Significant changes in lipid metabolism occur during these phases of catabolic and anabolic metabolism ashore and at sea. Adult females lose on average 32 % of their initial body weight during lactation (Carlini et al. 1997). For further details of the weight changes and lipid metabolism during lactation see Ramdohr et al. (this issue). The weight loss during the breeding and moulting period has to be compensated for by feeding at sea, although only about 50 % of the mass lost during lactation can be replaced during the pelagic phase between lactation and moult which lasts about 60 days (Carlini et al. 1997). The pelagic phase is interrupted by the moulting period and the weight loss during this additional time of fasting amounts to another 28 % of the animal's body weight (A. Carlini, IAA, Buenos Aires, personal communication).

The pelagic phase of the elephant seal represents the other 85 to 90 % of the elephant seal's life cycle, and only 10 % of this is spent on the surface. Southern elephant seals are able to dive to depths in excess of 1500 m and feed exclusively on cephalopods and fish. In contrast to most of the other populations of southern elephant seals which are currently declining, the King George colony remains stable. We therefore assume that the feeding grounds of this true Antarctic colony are more bountiful than that of most colonies elsewhere.

In the present study we investigated the movements of elephant seals from King George Island during their pelagic phase in order to identify their foraging areas during winter. We equipped seven juveniles (born October 1996) and 13 adult females with satellite transmitters (Wildlife Computers, Redmond, WA, USA and Telonics, Mesa, AZ, USA) between December 1996 and February 1997 after they had completed their moult. The transmitters were glued to the hair on the animals' backs (juveniles) or heads (adults) using a quick setting epoxy resin. We used a combination of ketamine, xylazin, and diazepam to immobilize the animals. The initial doses of the drugs were either adminstered by hand (juveniles) or by using a dart gun (adults) with automatic evacuating syringes (Telinject®, Römerberg, Germany). Maintenance of immobilization, which lasted between 1.5 and 3 h, was achieved by small additional doses of ketamine and/or diazepam administered by hand.

The animals left the colony between 2 and 14 days after they had been equipped with transmitters (ST-10 Telonics) or satellite-linked dive recorders (SDR T6 Wildlife Computers). These units are designed to provide at-sea locations through the Service ARGOS system (CLS / Service Argos, Toulouse, France) during the seal's foraging migrations (Fig. 1 and 2). While at sea the satellite-linked dive recorders also processed data about the seals diving behaviour in the form of histograms. These histograms are encoded into messages and transmitted to a polar-orbiting satellite (see Bengtson et al. 1993 for further details of the SDR-technology). The accessed data provide both the horizontal extent of the seal's migrations and the vertical distribution of their dive depths.

All the instrumented seals migrated south-west. Weaners travelled directly to the ice free area over the De Gerlache sea mountains (Fig. 1). The maximal extent of their range was 67°S 108°W. With increasing ice cover in mid April the juveniles again migrated northward reaching the area of the South Shetlands at the beginning of June. One juvenile was tracked until November, after it had reached the Patagonian shelf area in early September '97. Adult cows migrated close to the shelf region as far as 90°W, remaining for ca. five months in the Bellingshausen Sea near Alexander Island (Fig. 2).

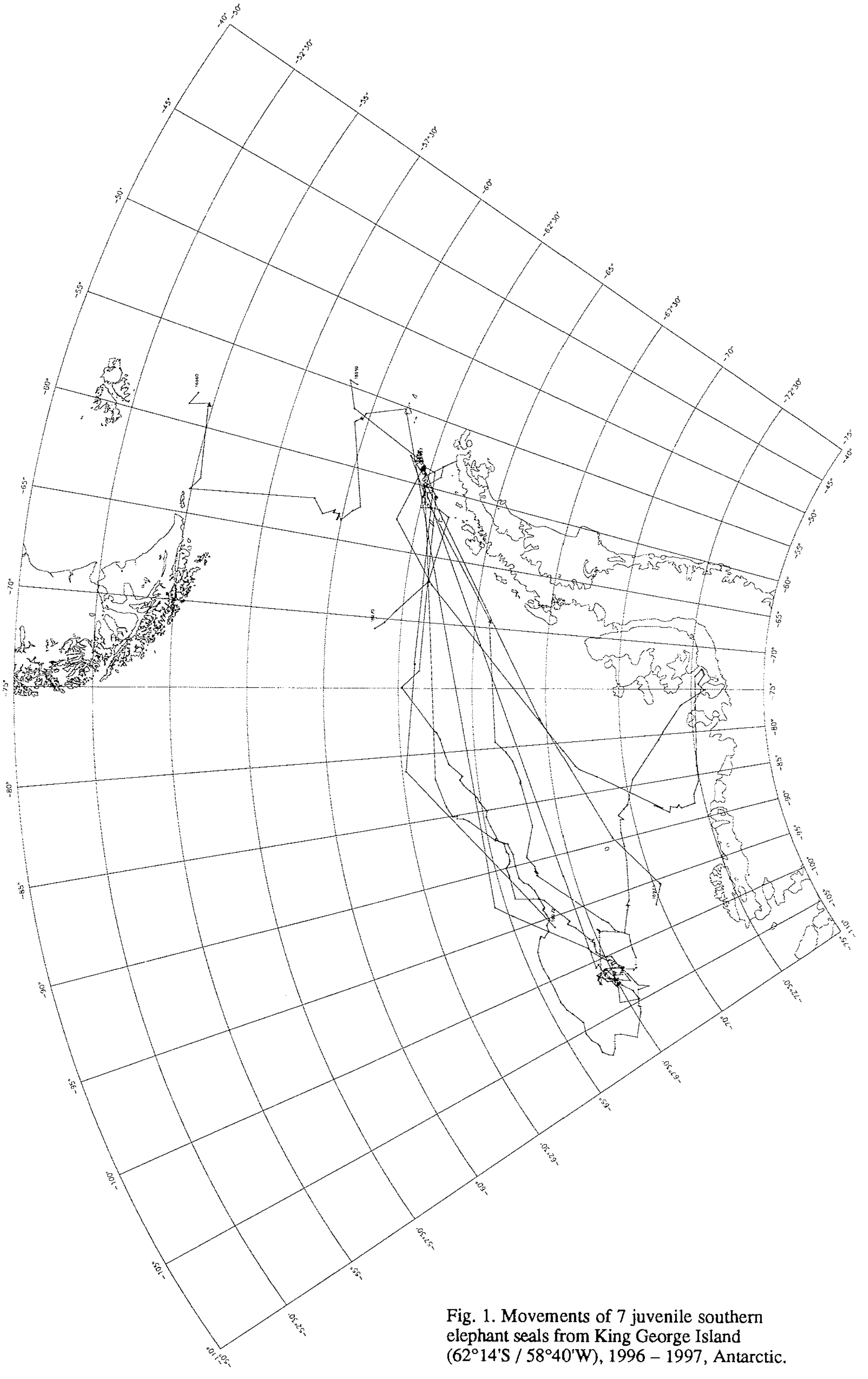

Fig. 1. Movements of 7 juvenile southern elephant seals from King George Island (62°14'S / 58°40'W), 1996 – 1997, Antarctic.

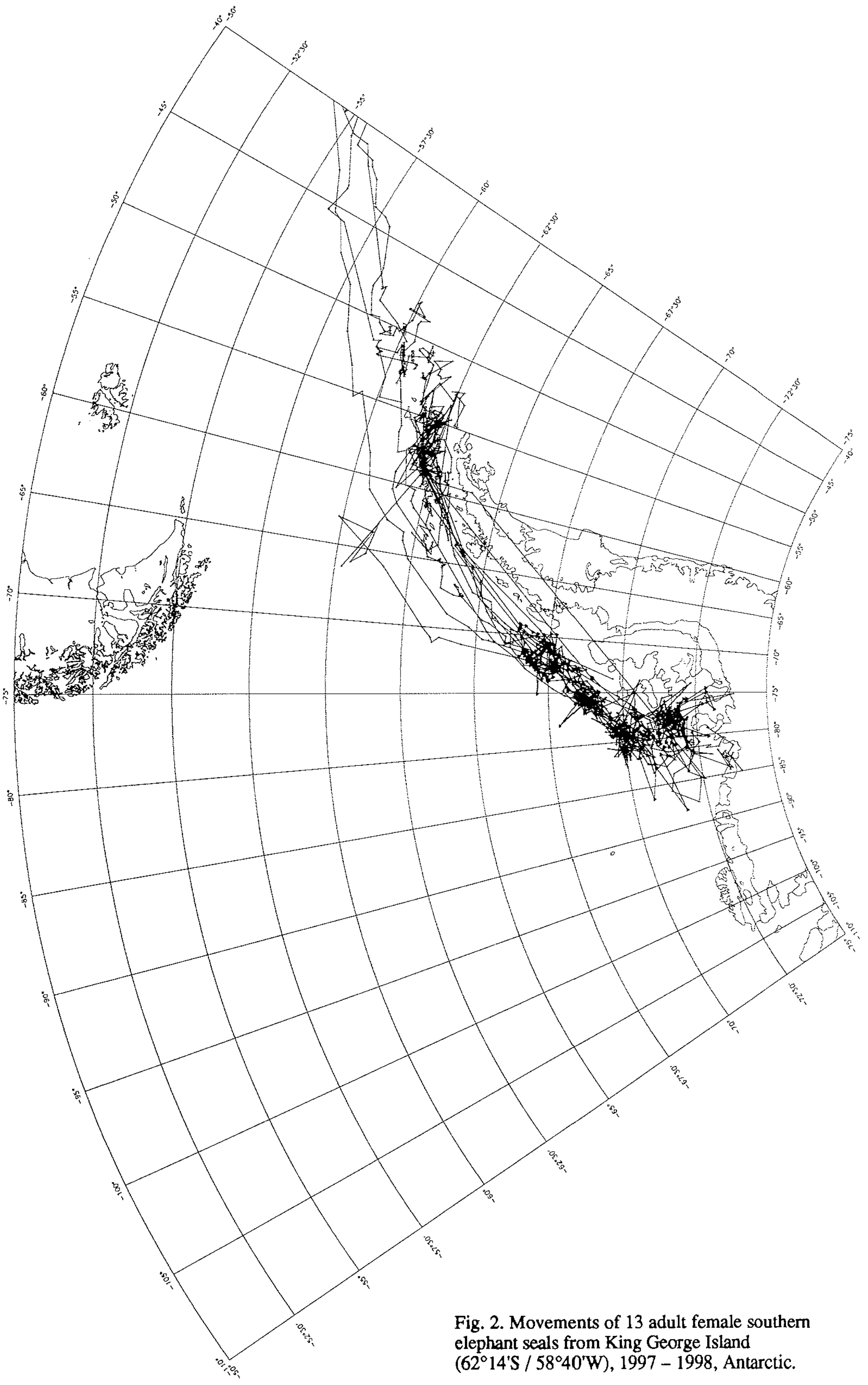

Fig. 2. Movements of 13 adult female southern elephant seals from King George Island (62°14'S / 58°40'W), 1997 - 1998, Antarctic.

After July ´97 the cows migrated northward and the first cows returned to the area of King George Island in September. Four cows were tracked until they reached the breeding colony in October, and 3 cows the transmitters of which failed during the period at sea have been resighted at King George Island. Table 1 gives the duration of tracking periods and the last recorded positions of the animals.

To obtain a comprehensive picture of the seals‘ foraging activity in a three-dimensional environment the data need to be interpreted in the context of both biological and physical parameters of the seal‘s marine environment. Therefore, a computer animation „Southern elephant seal migration and Antarctic sea ice“ was developed to relate the animals behaviour to sea ice cover (Kreyscher et al. in preparation). A QuickTime® (Apple Computer, Inc.) animation shows tracks of satellite tagged southern elephant seals in conjunction with seasonal changes in sea ice cover in the Antarctic Peninsula region from December 1996 – January 1998. The data of ice concentration are derived from the Special Sensor Microwave/Imager (SSM/I). The animation will be implemented in the homepage of the Alfred Wegener Institute for Polar and Marine Research (http://www.awi-bremerhaven.de). Location and diving behaviour data will be entered into the information system SEPAN (sediment and paleoclimate data network) of the Alfred Wegener Institute (Diepenbroek et al. 1996). This system guarantees longtime storage of the data in consistent formats and provides easy access for the scientific community via the World Wide Web or via a system specific client software with high functionality. The system is able to store raw data, evaluated data and all related meta-information necessary for their interpretation. The data generated by our studies on southern elephant seals are presently incorporated into SEPAN. The database contains selected data from WOCE and JGOFS as well as the GEBCO charts. The Atlas of the Southern Ocean (Olbers et al. 1992) will be incorporated soon and will enable us to analyse our data in relation to a fine-meshed network of hydrographic data (e.g. CTD-profiles). The visualization tools of SEPAN are able to relate the tracking and diving data of seals directly with hydrographic and bathymetric features "en route". The scientific interpretation of both the seal location and diving data and ice data will be published elsewhere.

Tab. 1 Tracking periods and last locations of southern elephant seals, Antarctic, 1996 - 1998

No.	Age	Sex	Start	End	Last location
1	J	M	04.12.96	10.12.96	62,20°S – 58,96°W
2	J	F	04.12.96	12.12.96	62,25°S – 58,68°W
3	J	M	05.12.96	03.07.97	61,62°S – 70,76°W
4	J	M	10.12.96	06.02.97	69,83°S – 97,40°W
5	J	F	10.12.96	21.02.97	65,92°S – 94,14°W
6	J	F	15.12.96	03.11.97	54,49°S – 58,45°W
7	J	M	17.12.96	05.06.97	59,25°S – 54,74°W
1	A	F	17.01.97	01.08.97	60,86°S – 58,88°W
2	A	F	18.01.97	17.10.97	62,24°S – 58,66°W
3	A	F	22.01.97	10.02.97	63,80°S – 58,97°W
4	A	F	24.01.97	30.01.97	62,90°S – 59,35°W
5	A	F	26.01.97	07.01.98 *	66,50°S – 70,28°W
6	A	F	09.02.97	12.04.97	62,06°S – 55,41°W
7	A	F	04.02.97	30.05.97	68,81°S – 76,21°W
8	A	F	09.02.97	04.01.98 *	69,94°S – 76,70°W
9	A	F	10.02.97	28.05.97	61,75°S – 55,07°W
10	A	F	10.02.97	23.02.97	67,74°S – 72,01°W
11	A	F	14.02.97	07.01.98 *	62,13°S – 55,41°W
12	A	F	14.02.97	28.04.97	70,71°S – 76,25°W
13	A	F	18.02.97	10.03.97	69,65°S – 75,80°W

J = juvenile A = adult F = female M = male * still transmitting (Jan. 98)

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Literature

Bengtson JL, Hill RD, Hill SE (1993) Using satellite telemetry to study the ecology and behavior of Antarctic seals. Korean Journal of Polar Research 4(2):109-115

Carlini AR, Daneri GA, Marquez MEI, Soave GE, Poljak S (1997) Mass transfer from mother to pups and mass recovery by mothers during the post-breeding foraging period in southern elephant seals (*Mirounga leonina*) at King George Island. Polar Biology 18(5):305-310

Diepenbroek M, Grobe H, Reinke M (1996) SEPAN – sediment and paleoclimate data network. In: Lautenschläger M, Reinke M (eds) Climate and Environmental Data Base Systems. Kluwer, Norwell pp 147–160

Olbers D, Gouretski V, Seiß G, Schröter J (1992) Hydrographic atlas of the Southern Ocean. Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

Population estimates of the birds of Potter Peninsula

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In a recent paper, Aguirre (1995) gives an overview of the birds he found at the Potter Peninsula, King George Island, during the 1987/88 and 1988/89 austral summers. With the presentation of his data he intended to contribute "...to facilitate protection and conservation of this diverse Antarctic seabird community..." (p.23). In order to support Aguirre's (1995) goal, we already corrected some mistakes in his paper (Hahn *et al.* in press). We here repeat some observations, mainly from the East German Antarctic Programme and our own surveys from the 1993/94, 1994/95, 1995/96 and 1997/98 seasons and present our population estimations of stormpetrels and skuas. We here try to provide a complete list of the birds of the Potter Peninsula as the numbers of breeding pairs and non-breeders are necessary for food web models.

Breeding species

Penguins, *Pygoscelis* spp.

From three seasons, we provide further data on penguin numbers that were obtained by direct counting. Table 1 summarizes published penguin numbers at Stranger Point with the addition of a few unpublished data.

Unfortunately, we did not follow the population development of the penguin species and are, therefore, not able to present more recent data.

Southern Giant Petrel, *Macronectes giganteus*

Additionally to the 75 breeding pairs mentioned by Aguirre (1995) for the 1988/89 season, which are very similar to the 78 pairs found by Araya & Arieta (1971) in the summer 1966/67, a few further records exist. In the 1983/84 season, about 120 occupied nests were found between Three Brothers Hill and Stranger Point (Lorenz 1985) and Peter *et al.* (1988) counted ca. 59 pairs at the same site. The most recent count in February 1998 revealed a total of 46 occupied nests (Peter, Quillfeldt & Schmoll, unpubl. data).

Pintado Petrel, *Daption capense*

Aguirre (1995) did not mention this species as breeding. In an unpublished report, three breeding pairs were recorded in February 1986 at Stranger Point (Zippel 1986).

Wilson's Storm Petrel, *Oceanites oceanicus*

For the estimation of the colony sizes of Wilson's Storm Petrel by the method of Copestake *et al.* (1988) see Hahn *et al.* (in press). The number of breeding pairs can be estimated from capture-recapture data if breeding females are distinguished by their larger cloaca at the time before and after egg-laying. We estimate a total of 1400 to 2280 breeding pairs around Three Brothers Hill.

The numbers estimated by us correspond fairly well to each other and exceed

Araya & Arieta's (1971) data. They found 500 nests around Three- Brothers- Hill and 30 around Stranger Point. Our data largely exceed those given by Aguirre (1995) who, on the one hand, assumed an average population size of 25 with a range from 1 to 222 but also gave a figure of 100 to 200 nests (Table 1 in Aguirre 1995).

Since Aguirre (1995) did not provide breeding data, we add some observations from the 1995/96 summer season. The laying period was spread from 16 December to 15 January, hatching occurred from 23 January to 1 March, and departure, if this term refers to fledging, started from 11 March the latter being similar to Aguirre's (1995) figure (5 March). The linear regression of the proportion of young still in the nest (y) gives the following function: $y = 102.4 - 2.81\ x$ ($P = 0.004$), where x are days after the first hatching event. The value $y = 0$ is reached at $x = 36.4$ days. This equals an end of the fledging period at 15 April. Departure of adult breeding birds occurs at the same time.

Blackbellied Storm Petrel, *Fregetta tropica*

Araya & Arieta (1971) did not find Blackbellied Storm Petrels during their survey, while Aguirre (1995) observed several around Three Brothers Hill but the breeding status needed confirmation.

In the 1994/95 season, we caught 26 specimens. Three nocturnal surveys covering the major part of the peninsula were carried out in January 1995, when we estimated there to be approximately 350 to 400 callers around Three Brothers Hill, two at Stranger Point and one near Jubany Station. In the following season, in January 1996, we counted about 300 calling birds on three surveys but mist-netted 166 birds and found 32 in their cavities. Since the recapture rate of birds banded in the 1994/95 season was low, being six birds out of 26 (23%) in 1995/96 (one from the same cavity where it was ringed the year before) and the percentage of breeders among the callers is unknown, we applied Bailey's modification of the Lincoln Index as described for the Wilson's Storm Petrel (Copestake *et al.* 1988) and above. The time of greatest cloacal width was found to be from 18 to 28 January 1996. In 16 mist-netting nights (until 17 February 1996) 103 specimens were caught, 26% of which had a cloaca wider than 7.0 mm. Nineteen were recaptured. The average value of the population size from 16 nights was then calculated to be 213 ± 61 (S.E.) birds. The area in which we carried out the trapping corresponded to about one third to one fourth of the total area around Three Brothers Hill which was suitable for breeding. The total number of birds that we estimate on this base is 639 to 852 birds. From this figure, we were not able to deduce the total number of breeding birds, because only 13 nest sites were found. However, from the cloaca data, 26% of the birds appeared to be breeding females. Given equal activities of the two sexes, this would indicate that about half of the birds caught might have been breeding individuals.The first egg was found on 27 December 1995. The hatching period was between 4 and 25 February 1996. Derived from chick masses on 20 March 1996 (70.4 to 105.0 g, N= 6), the departure time of the adults is assumed to be around mid-April.

Blue-eyed Shag, *Phalocrocorax atriceps*

This species is an occasional breeder at Stranger Point as is indicated by the record of "one or two breeding pairs" from 18 January 1985 (Peter et al. 1988). In 1997/98, as in other years, some breeding pairs were observed on small islets off Stranger Point (Barrera-Oro, pers. comm.).

Greater Sheathbill, *Chionis alba*

Araya & Arieta (1971) found two nests and estimated the total number to about 30. Twelve breeding pairs are mentioned by Peter et al. (1988) for the season 1984/85, 14 were found the next season (Zippel 1986). In the 1987/88 season, Favero (1993a) found 6 breeding pairs. Favero (1993b) published an entire paper on chick growth and nesting ecology of this species on Potter Peninsula and two other places. Recently, Favero (1996) reports on the foraging ecology of the Sheathbill on Potter Peninsula.

South Polar Skua, *Catharacta maccormicki*

In population surveys 1993/94, 1994/95 and 1997/98, we attempted to mark all nests. Totals of 40, 41, and 44 nests were found, respectively. In addition, four, five and six territories without nests were located in the respective years. The median hatching date was 28 December 1993 (one-egg and two-egg clutches combined). Aguirre (1995) did not differentiate between the skua forms for nonbreeders. For breeders, he records two nests in the text but 20 in his Table 1. Older records exist in Araya & Arieta (1971) and Peter *et al.* (1988) who both found one pair in the close vicinity of Stranger Point.

Subantarctic Skua, *Catharacta antarctica lonnbergi*

In the breeding seasons 1993/94, 1994/95 and 1997/98, 35, 29 and 26 nests were marked, respectively. One territory was found without a nest (1994/95), three such territories in 1997/98. The median hatching date, combined for one-egg and two-egg clutches, was the 28 December 1993 and was similar to the one found by Aguirre (25 December) who recorded a total of 20 nests.

Peter *et al.* (1988) mention six breeding pairs from the coastal plain at Stranger Point. Araya & Arieta (1971) found only eight pairs, including one trio on Potter Peninsula.

Mixed pairs, *Catharacta antarctica* x *Catharacta maccormicki*

In the 1993/94 season, 10 mixed pairs of Subantarctic and South Polar Skua or of a hybrid with either skua form were found. Seven such pairs were recorded in the summer of 1994/95, thirteen in 1997/98.

Another type of mixed pair was mentioned by Reinhardt *et al.* (1997) who found a pair of South Polar Skua and a hybrid of South Polar Skua x Chilean Skua at Potter Peninsula. This individual was still observed in the 1997/98 season.

Altogether, 85 skua nests were found in 1993/94, 77 in 1994/95, and 83 in 1997/98. Furness (1982) compared the census techniques of skua colonies for the Great Skua *Catharacta skua* of the Northern Hemisphere. He found the method of marking nests as the most exact one. Both counting nests by recording the aggressive behaviour in territories and counting apparently occupied territories underestimate the actual number of nests. Although Aguirre (1995) did not mention his census method it appears that he did not fully cover the whole peninsula nor did he correctly apply either technique. This resulted in a nearly four-fold lower number of skua nests in his study. In the absence of diseases as e.g. fowl cholera (Parmelee *et al.* 1979) the number of breeding pairs of the Subantarctic Skua appears to be fairly stable over several years (Peter *et al.* 1990), whereas that of the South Polar Skua is more variable.

Kelp Gull, *Larus dominicanus*
Aguirre (1995) mentions 44 breeding pairs and considered this the first published record. However, at least ten breeding pairs were estimated by Araya & Arieta (1971), twenty-five on 18 January 1985 by Peter *et al.* (1988), and at least 15 the year after (Zippel 1986).

Antarctic Tern, *Sterna vittata*
Peter et al. (1988) recorded about 55 breeding pairs at Stranger Point. Favero (1994) found 358 breeding pairs during the 1987/88 season. For the same season and the same site, Aguirre (1995) estimated the number to be about 200 pairs. A recent estimation in 1997/98 revealed about 250 breeding pairs, including a few on top of Three Brothers Hill.

Non-breeding species

Macaroni Penguin, *Eudyptes chrysolophus*
Peter *et al.* (1988) recorded this species from 8 March 1984, a specimen that had been banded by Brazil ornithologists on 2 February 1984 (M. Sander, pers. comm.). H.-U. Peter (unpubl.data) observed another unmarked individual in January 1994 at Stranger Point.

Wandering Albatross, *Diomedea exulans*
Peter *et al.* (1988) recorded one individual near Stranger Point on 20 March 1985.

Snow Petrel *Pagodroma nivea*
Between 10 and 12 October 1987, Nadler & Mix (1989) counted 250 to 300 birds during five hours of observation flying past at Stranger Point.

Antarctic Fulmar, *Fulmarus glacialoides*
Between October 10, and 17, 1987, Nadler & Mix (1989) observed daily three to six birds, with a maximum of about 300 birds on 16 October 1987 flying past close to the edge of the pack ice.

Antarctic Petrel, *Thalassoica antarctica*
Nadler & Mix (1989) observed single birds flying southwards on 12, 16, and 17 October at Stranger Point.

Prions, *Pachyptila sp.*
In January 1994, a skull and parts of two wings of a prion species were found on the beach. The species identity could not be confirmed.

Leach's Storm Petrel, *Oceanodroma leucorhoa*
The first Antarctic record of this species on 22 February 1996 from the Potter Peninsula is given by Hahn & Quillfeldt (in press). The bird was caught by mistnet and had a bare brood patch.

Cattle Egret, *Bubulcus ibis*
Additional records to those given by Aguirre (1995) are to be found in Silva *et al.* (1995) for the Stranger Point region.

Yellowbilled Pintail, *Anas georgica*
In addition to Aguirre's (1995) data, the wing of a dead individual was found by us in the 1995/96 season.

Blacknecked Swan, *Cygnus melancoryphus*
Four individuals were observed by us in the summer of 1995/1996. Aguirre (1995) and Silva *et al.* (1995) report on earlier observations.

Whiterumped Sandpiper, *Calidris fuscicollis*
Silva *et al.* (1995) additionally record five and two birds from Stranger Point in December 1993 and January 1994, respectively.

Chilean Skua, *Catharacta chilensis*
On 6 December 1993, a bird which was morphologically indistinguishable from the Chilean Skua was observed and photographically documented at Potter Peninsula (Reinhardt *et al.*, 1997).

Arctic Tern, *Sterna paradisaea*
During December and January 1993/94 and 1994/95, several terns in nonbreeding plumage without any brownish colouration patterns on the back or the wings were observed. They are, therefore, unlikely to be juvenile Antarctic Terns and were probably Arctic Terns, but remain unconfirmed.

Barn Swallow, *Hirundo rustica*
Two Barn Swallows were transported from Buenos Aires to the Potter Cove by the icebreaker Almirante Irizar. During the exchange period of station personal, the two swallows were observed flying over the Potter Cove for at least two minutes in the evening hours of 29 and 30 November 1993.

Discussion

We here report a further three species of at least occasional breeders, increasing the number of known breeding species for the Potter Peninsula to 12. Also for nonbreeders the Potter Peninsula appeares to be more important than previously reported (Araya & Arieta 1971, Aguirre 1995) with our additional records of seven species, including an unidentified prion and the unconfirmed observations of Arctic Terns. The total number of bird species now reaches 27.

The record of Leach's Storm Petrel (Hahn & Quillfeldt, in press), the five- to 10-fold higher breeding number estimates of Wilson's Storm Petrel and a much higher number of Blackbellied Storm Petrels (in comparison to Aguirre 1995) were found through intensive nocturnal mist-netting. Mist-netting was not applied by Aguirre (1995). The methods applied by Aguirre (1995) were probably not appropriate for the census of several species. For instance, South Polar Skuas tend to nest further inland when sympatric with Subantarctic Skuas (Peter *et al.* 1990). This might explain why Aguirre (1995) found only two pairs with his "near-coast-censuses". The Subantarctic Skuas that nest closer to the coast (Peter *et al.* 1990), to the station and to penguin colonies are easier to record but nevertheless seem to be more a more abundant breeder than was shown by Aguirre (1995). We conclude that the differences between our data and Aguirre's (1995) are rather due to methodology than to actual changes in the abundances of the species.

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References

Aguirre C A (1995) Distribution and abundance of birds at Potter Peninsula, 25 de Mayo (King George) Island, South Shetland Islands, Antarctica. Mar. Orn. 23: 23-31.

Araya B, Arieta A (1971) Las Aves de Caleta Potter, Isla Rey Jorge, Antartica Chilena- Censo y distribution. Rev. Biol. Mar., Valparaiso 14: 121-128.

Copestake P G, Croxall J P, Prince P A (1988) Use of cloakal sexing techniques in mark-recapture estimates of breeding population size in Wilson's Stormpetrel *Oceanites oceanicus* at South Georgia. Polar Biol. 8: 271-279.

Croxall J P, Kirkwood E (1979) The distribution of penguins on the Antarctic Peninsula and Islands of the Scotia Sea. Cambridge: British Antarctic Survey.

Favero M (1993a) Asociaciones alimentarias de la Paloma Antárctica *Chionis alba* en las islas 25 de Mayo (King George Is.) y Media Luna (Halfmoon Is.), Shetland del Sur. Actas II Jor. Com. Inv. Cient. Ant. 2: 55-58.

Favero M (1993b). Biologia reproductiva de la Paloma Antárctica *Chionis alba* (Charadriiformes) en las Islas Shetland del Sur, Antartida. Riv. ital. Orn. 63: 33-40.

Favero M (1994) Biologia reproductiva del gaviotín antártico, *Sterna vittata*, en península Potter, Isla 25 de Mayo (King George), Islas Shetland del Sur, Antártida. Riv. ital. Orn. 64: 62-70.

Favero M (1996) Foraging ecology of pale-faced sheathbills in colonies of Southern Elephant seals at King George Island, Antarctica. J. Field Or. 67: 292-299.

Furness R W (1982) Methods used to census skua colonies. Seabird Rep. 6: 44-47.

Hahn S, Quillfeldt P (in press) First record of Leach's Storm Petrel (*Oceanodorma leucorhoa*) at King George Island, South Shetland Islands. Mar. Orn.

Hahn S, Peter, H.-U, Quillfeldt P, Reinhardt, K (in press) The birds of the Potter Peninsula, King George Island, South Shetland Islands, 1971 - 1996. Mar. Orn.

Jablonski B (1984) Distribution and numbers of penguins in the region of King George Island (South Shetland Islands) in the breeding season 1980/81. Pol. Polar Res. 5: 17-30.

Lorenz H (1985) Wissenschaftlicher Bericht über die Teilnahme an der 28. Sowjetischen Antarktisexpedition Station Bellingshausen 1982-1984. Berlin: unpubl. report, 41 pp.

Müller-Schwarze D, Müller-Schwarze D (1975) A survey of twenty-four rookeries of pygoscelid penguins in the Antarctic Peninsula. In: Stonehouse, B. (Ed.) The biology of penguins. London: Macmillan, pp. 309-320.

Nadler T, Mix H (1989) Wissenschaftlicher Bericht über die Teilnahme ander 32. SAE. Berlin: unpubl. report. 67 pp.

Parmelee D F, Maxson S J, Bernstein N P (1979) Fowl cholera outbreak among brown skuas At Palmer Station. Antarct.J.U.S. 14: 168-169.

Peter H-U, Kaiser M, Gebauer A (1988) Untersuchungen an Vögeln und Robben auf King Geoge Island, South Shetland Islands, Antarktis. Geodät. Geophysikal. Veröff.. R.I 14: 1-127.

Peter H-U, Bannasch R, Bick A, Gebauer A, Kaiser M, Mönke R, Zippel D (1989) Bestand und Reproduktion ausgewählter antarktischer Vögel und Robben im Südwestteil von King George Island, South Shetland Islands. Wiss. Z. Univ. Jena, Naturwiss. R. 38: 645-657.

Peter H-U, Kaiser M, Gebauer A (1990) Ecological and morphological Investigations on South Polar Skuas (*Catharacta maccormicki*) and Brown Skuas (*Catharacta skua lonnbergi*) on Fildes Peninsula, King George Island, South Shetland Islands. Zool. Jahrb. Abt. Syst. Ökol. Geogr. Tiere 117: 201-218.

Reinhardt K, Blechschmidt K, Peter H-U, Montalti D (1997) A hitherto unknown hybridization between Chilean and South Polar Skua. Polar Biol. 17: 114-118

Shuford W, Spear L (1988a) Surveys of breeding penguins and other seabirds in the South Shetland Islands, Antarctica, January-February 1987. Antarctic Marine Living Resources Program. National Oceanic and Atmospheric Administartion Technical Memorandum National Marine Fisheries Service-F/NEC-59. (cited in Aguirre (1995), not available to the authors of the present paper).

Shuford W, Spear L (1988b) Surveys of breeding chinstrap penguins in the South Shetland Islands, Antarctica. Br. Antarct. Surv. Bull. 81: 19-30.

Silva M P, Coria N C, Favero M, Casaux R J (1995) New records of Cattle Egret Bubulcus ibis, Blacknecked Swan Cygnus melancorhyphus and Whiterumped Sandpiper Calidris fuscicollis from the South Shetland Islands, Antarctica. Mar. Ornithol. 23: 65-66.

Zippel D (1986) Teilbericht (Ornithologie) über die wissenschaftlichen Ergebnisse während der 30. SAE im Untersuchungsgebiet King George. Berlin: unpubl. report 65 pp.

Table 1:
Number of penguin breeding pairs at Stranger Point, Potter Peninsula

Season	Adelie *P. adelie*	Gentoo *P. papua*	Chinstrap *P. antarctica*	Reference
1965/66	6440	2920	950	White (in Croxall & Kirkwood 1979)
1966/67	~15000 adults	~ 3000 adults	~ 2200 adults	Araya & Arieta (1971)
1971/72	~ 18000	~ 1000	~ 200	Müller-Schwarze&Müller-Schwarze (1975)
1980/81	18412	2584	495	Jablonski (1984a)
1984/85	17000	1900	350	Peter *et al.* (1988)
1985/86	16-17000	2500	500	Zippel (1986)
1986/87	?	1500-2000	150-200	Shuford & Spear (1988a), as cited in Aguirre (1995)
1986/87	?	?	75-100	Shuford & Spear (1988b)
1987/88	14100/15491			Nadler & Mix (1989)/Aguirre (1995)
1988/89	14554	2325	265	Aguirre (1995)

STUDIES ON THE BACTERIAL FLORA ASSOCIATED TO THE BROWN SKUA (*Catharacta antarctica lonnbergi*).

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Introduction

The bacterial flora associated to terrestrial and aquatic organisms plays an important role in their normal physiology and has been studied in almost all the taxonomic groups of plants and animals (Prieur, 1991). In many cases, this flora reflects the bacteriological characteristics of the environment in which the organisms are living, as well as the bacteriological composition of the diet in the case of gut flora (Soucek and Mushin, 1970). In addition, bacterial pathologies of diverse animals as bivalves, birds, mammals and other groups have been studied and reported (Varaldo et al., 1988, Kudo et al., 1988; Buck, 1990).
The Brown Skua (*Catharacta antarctica lonnbergi*) is an Antarctic and sub-Antarctic circumpolar specie distributed along the Scotia Arch Islands and the Antarctic Peninsula until 65°S, and form breeding colonies in coasts. In relation to the feeding behaviour, several authors have mentioned their predatory and kleptoparasitic habits on many different organisms (Osborne, 1985, Pietz, 1987).
Given that this specie obtains an important fraction of its food from the human stations, it has been suggested that the ingestion of pathogenic bacteria present in these residues could be one of the main factors causing massive death of individuals in Antarctica (Parmelee et al., 1979; Montalti et al., in press). In addition, the Brown Skua shares some breeding areas with the South Polar Skua (*Catharacta maccormicki*) but they differ in the feeding behaviour, as the South Polar Skua feeds almost exclusively in the sea, while the Brown Skua is a frequent predator of the penguin rookeries. The knowledge of the digestive tract indigenous bacterial flora of these two species could give in the future an important tool in order to differentiate them or to compare them with other groups of birds.
The aim of this study was to analyse the normal heterotrophic bacterial flora obtained from the digestive tract of the Brown Skua and evaluate the eventual presence of pathogenic strains.

Methodology

Three adult specimens of Brown Skua were collected between December and March, nearby Jubany Scientific Station, Potter Peninsula, King George Island, South Shetland Islands (62°14'S, 58°40'W). As a part of the several studies carried out with these specimens, the composition of the microflora of the digestive tract was investigated. Small portions of tissue were taken from the stomach, middle intestine and cloaca, placed in sterile tubes containing 1 g of sterile sand and 5 ml of sterile diluent (1 g/l of peptone solution) and shaken vigorously for 15 min. From each sample, serial decimal dilutions were prepared in the same diluent and 0.1 ml of these dilutions were spread (on duplicate) on plates containing nutrient agar, McConkey agar and Desoxycholate-lactose-sucrose (DCLS) agar. Plates were incubated at 37°C for 48 h and the quantitative results were expressed as colony forming units per millilitre (CFU/ml). Colonies were isolated, purified by re-streaking twice and classified on the basis of the morphological and biochemical characteristics listed in table 1.

Birds identification was made on the basis of their coloration and morphometry. The index used by Peter et al. (1990) was calculated and the sizes of culmen and tarsus were measured according to Baldwin et al. (1931).

Table 1. Morphological and biochemical tests used to identify the isolates obtained from the gastrointestinal tract of the Brown Skuas on nutrient agar, McConkey agar and DCLS agar plates.

- Gram stain.
- Morphology (phase-contrast microscopy).
- Mobility (phase-contrast microscopy and semi-solid medium (SIM)).
- Production of: Catalase.
    - Oxidase.
    - Urease.
    - Phenylalanine deaminase.
    - Arginine dehydrolase.
    - Ornithine decarboxylase.
    - Lysine decarboxylase.
- Methyl red test.
- Voges Proskauer reaction.
- Indole test (SIM medium).
- Nitrate reduction.
- Utilisation of: Glucose (O/F medium).
    - Citrate.
    - Lactose.
- SH_2 production (SIM and TSI media).
- Growth in: Cetrimide agar.
    - Levine agar.

Results and Discussion

Average body weight of the analysed adult specimens was 1531±152 g (X ± SD). The stomach of specimens 1 and 2 was full. Inside the first of them we founded otoliths and scales from fishes and feathers from adult penguins. Inside the second, feathers and small bones of young penguins were predominant. The third skua had the stomach empty. None of the specimens had endoparasites in the digestive tract as was reported by Hoberg (1983) for the birds around Palmer Station. The quantitative analysis of the bacterial flora from the different portions of the digestive tract is shown in table 2 and the taxonomic groups are shown in table 3. Stomach samples showed extremely variable counts (table 2) and the generic composition of the bacterial flora also showed important differences between specimens (table 3). This bacterial flora seems to be strongly influenced by the diet habits and the repletion degree, as was suggested by Soucek and Mushin (1970) for different Antarctic birds and mammals. Only in the stomach tissue of specimen 1 a high percentage of *Pseudomonas* spp was observed, which is in agreement with the observation of the presence of fish remains in stomach contents. It is known that this genus is always present in Antarctic fishes and is the predominant genus in the coastal seawater, where these fishes can be captured by the skuas (Mac Cormack and Fraile, 1990). Moreover, the low bacterial counts present in the specimen 3 could be related with the absence of food. In contrast with that found in stomach, counts from intestine and cloaca showed more constant values between specimens, probably because portions of the digestive tract suffer a lesser influence of the external bacterial flora than the stomach.

Table 2. Heterotrophic bacterial counts (CFU/ml) from the digestive tract of the brown skua cultured on different culture media.

Specimen	Culture media	Stomach	Intestine	Cloaca
1	Nutrient agar	2.0×10^5	5.1×10^3	1.4×10^4
	McConkey agar	1.3×10^5	4.5×10^3	8.3×10^3
	DCLS agar	1.3×10^5	3.5×10^3	ND
2	Nutrient agar	3.4×10^3	8.2×10^3	6.0×10^3
	McConkey agar	3.1×10^3	7.0×10^3	6.2×10^3
	DCLS agar	ND	ND	ND
3	Nutrient agar	7.5×10^2	6.4×10^3	5.0×10^3
	McConkey agar	6.6×10^2	5.5×10^3	2.9×10^3
	DCLS agar	ND	ND	ND

ND: Not detected.

Table 3. Qualitative analysis of the bacterial flora isolated from the digestive tract of *C. lonnbergi*. All data are expressed in percentage (%) of total isolates. S: stomach, I: Intestine, C: Cloaca.

Bacterial group	Specimen 1			Specimen 2			Specimen 3		
	S	I	C	S	I	C	S	I	C
E. coli	43	70	79	100	99	98	19	100	14
Pseudomonas spp.	40	25	-	-	-	-	-	-	-
Unidentified Gram (-) bacilli	14	-	16	-	-	2	-	-	-
Unidentified Gram (+) bacilli	2	5	-	-	-	-	-	-	5
Micrococcus spp.	1	-	-	-	1	-	-	-	-
Acinetobacter spp.	-	-	5	-	-	-	-	-	13
Staphylococcus epidermidis	-	-	-	-	-	-	81	-	68

Escherichia coli was predominant in the majority of the samples, and represented the 70-100% of the total intestinal bacterial flora. The predominance of *Staphylococcus epidermidis*, as was found in specimen 3, was observed previously in Antarctic birds (Clarke and Kerry, 1993) and could be related to the scarce development of the ingigenous bacterial flora when feeding is abnormal.

Finally, bacterial strains like *Pasteurella multocida, Pseudomonas pseudomallei, Salmonella* sp and *Erysipelothrix* sp, quoted as pathogenic for Antarctic birds (Clarke and Kerry, 1993), were not isolated from the studied specimens.

References

Baldwin, S.P., Obelholser, H.C., Worley, L.G. 1931. Measurements of birds. Scient. Pub. Cleveland Mus. Nat. Hist. 2: 1-165.

Buck, J.D. 1990. Isolation of *Candida albicans* and halophilic *Vibrio* spp. From aquatic birds in Connecticut and Florida. Appl. Environ. Microbiol. 56: 826-829.

Clark, J., Kerry, K. 1993. Disease and parasites of penguins. Korean J. Polar Res.4:79-96.

Hoberg, E.P. 1983. Preliminary comments on parasitological collections from seabirds at Palmer Station, Antarctica. Antarct. J. U. S. 18: 206-208.

Kudo, T., Hatai, K., Seino, A. 1988. *Nocardia seriolae* sp. nov. causing nocardiosis of cultured fish. Intern. J. System. Bact. 38: 173-178.

Mac Cormack, W.P. Fraile, E.R. 1990. Bacterial flora of newly caught Antarctic fish *Notothenia neglecta*. Polar Biol. 10: 413-417.

Montalti, D., Coria N.R., Curtosi, A. Unusual deaths of subantarctic skuas *Catharacta antarctica* at Hope Bay, Antarctica. Mar. Ornith.(In Press).

Osborne, B.C. 1985. Aspects of the breeding biology and feeding behaviour of the brown skua *Catharacta lonnbergi* on Bird Island, South Georgia. Brit. Antarct. Surv. Bull. 66: 57-71.

Parmelee, D.F., Maxson, S.J., Bernstein, N.P. 1979. Fowl cholera outbreak among brown skuas at Palmer Station. Antarct. J. U. S. 14: 168-169.

Peter, H.U., Kaiser, M., Gebauer, A. Ecological and morphological investigations on south polar skuas (*Catharacta maccormicki)* and brown skuas (*Catharacta lonnbergi*) on Fildes Peninsula, King George Island, South Shetland Island. Zool. J. Syst. 117: 201-218.

Pietz, P.J. 1987. Feeding and nesting ecology of sympatric south polar and brown skuas. Auk. 104: 617-627.

Prieur, D. 1991. Interactions between bacteria and other organisms in the marine environment. In: Rheinheimer et al. (Eds). Distribution and activity of microorganisms in the sea. Kieler Meeresforschungen, Sonderheft N°8. Pp 231-239. Kiel.

Soucek, Z., Mushin, R. 1970. Gastrointestinal bacteria of certain Antarctic birds and mammals. Appl. Microbiol. 20: 561-566.

Varaldo, P.E., Kilpper-Balz, R., Biavasco, G., Satta, G., Schleifer, K.H. 1988. *Staphylococcus delphini* sp. nov., a coagulase positive species isolates from dolphins. Inter. J. System. Bact. 38: 436-439.

3. ECOPHYSIOLOGICAL STUDIES ON KEY ORGANISMS IN THE ECOSYSTEM

CO_2 exchange of two chionophilous lichens in the maritime Antarctic - preliminary results

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In the maritime Antarctic lichens and bryophytes form the dominant element of the vegetation. In such extreme environments primary production depends substantially on the physiological capability of the organism to survive under the prevailing environmental conditions (SCHROETER et al. 1995). Low destruction rates and the abscense of grazing by vertebrates allow accumulation of a considerable standing biomass of values up to 1.89 kg dry weight m^{-2} for *Usnea-Himantormia* mats in the maritime Antarctic (KAPPEN 1993a). These taxa are preadapted to metabolise at low temperatures and are tolerant to frequent and rapid freeze-thaw and hydration-dehydration cycles (SMITH 1990a). Due to their poikilohydrous nature lichens depend strictly on water absorption from ambient moisture provided by rainfall, dew, mist and fog, or meltwater. For lichen thalli, water uptake is not only possible from melt water but also from snow crystals at temperatures below 0°C (KAPPEN 1989, KAPPEN 1993b, SCHROETER et al.1994, SCHROETER & SCHEIDEGGER 1995). Photosynthetic activity of lichens is possible below the freezing point (Lange & Metzner 1965, KAPPEN 1989, SCHROETER et al. 1994, KAPPEN et al. 1996) and even under a snow layer up to 15 cm light intensity is high enough to enable positive CO_2 balance (KAPPEN & BREUER 1991). Various authors (SELKIRK & SEPPELT 1987, KAPPEN et al. 1990, SMITH 1990b) mentioned snow as an important factor that influences the vegetation development and vegetation pattern.

As a preliminary result we present here the photosynthetic response of two typical lichens to different light and temperature conditions. These maritime Antarctic species represent different growth forms. The blackisch fruticose lichen *Himantormia lugubris* (Hue) Lamb. occurs mainly on wind-swept plateaus but in the moister parts of a lichen heath dominated by *Usnea aurantiaco-atra*. The chionophilous crustose lichen *Lecidea sciatrapha* Hue colonizes boulders as well as small pebbles in sheltered depressions where snow accumulates during winter and spring. The material was collected at the foot of the southern slopes of the Tres Hermanos (for a sketch map see 'Seasonal variation of abiotic factors in terrestrial habitats' (Winkler et al.)).

CO_2 exchange was measured by means of an infrared gas analyser (Binos, Leybold-Heraeus, Germany) in an open-flow minicuvette gas exchange system (Walz, Germany) under different temperature and light conditions. Lichen thalli were moistened by spraying with either melt water (pH 7; *Himantormia lugubris)* or de-ionized water (*Lecidea sciatrapha).* Photosynthesis of *Himantormia lugubris* was measured within a temperature range from -5°C to +20°C (5K steps) and irradiances up to 1300 µmol m^{-2} s^{-1} PPFD (Photosynthetic Photon Flux Density). Due to technical constraints it was merely possible to measure CO_2 exchange of *Lecidea sciatrapha* at temperatures between -5°C and +10°C. However, these temperatures are typically occuring in the habiat of both lichens and therefore this temperature range is of main ecological importance for their primary production. The experiments were carried out at Jubany Station and in the laboratory in Kiel respectively.

The net photosynthetic response of *Himantormia lugubris* is shown in Fig. 1. The light compensation point increased dramatically with increasing temperature until +20°C where respiration could only be compensated by irradiances higher than 300 µmol m^{-2} s^{-1} PPFD. Light saturation was reached near 600 µmol m^{-2} s^{-1} PPFD at -5° and 0°C. At +10°C net photosynthesis was saturated beyond 900 µmol m^{-2} s^{-1} PPFD. At +15°C it seemed as if a saturation was reached already at 500 µmol m^{-2} s^{-1} PPFD but this might be an effect of the more rapid desiccation at high light intensities at this temperature. In their natural habitat active i.e. moist thalli may not heat higher than +15°C. But positive net photosynthesis was still possible at +20°C (Fig. 1b). Optimum temperature for photosynthesis at PPFD higher than 75 µmol m^{-2} s^{-1} is slightly shifting from +3° to +8°C.

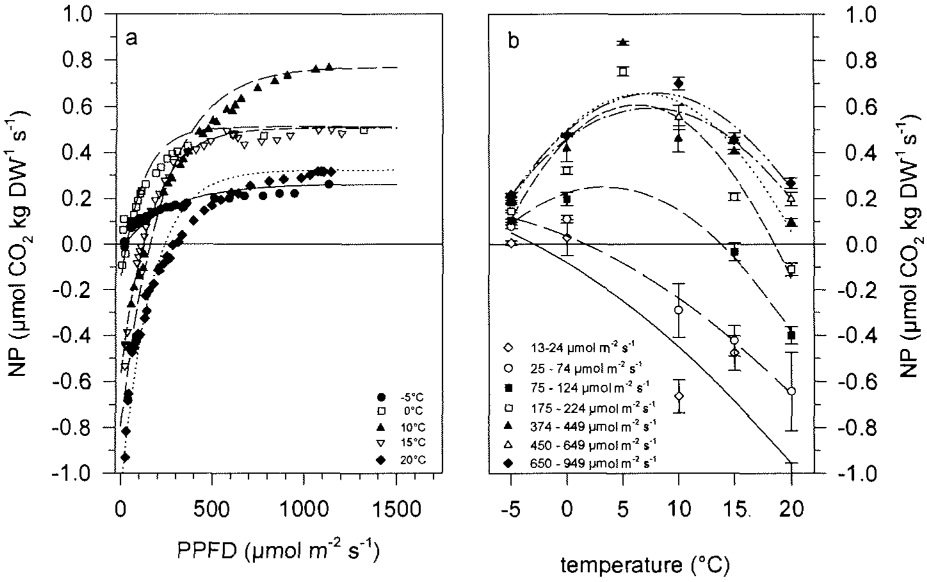

Fig. 1: Light (Fig. 1a) and temperature (Fig. 1b) dependent CO_2 exchange of *Himantormia lugubris*. The data were calculated on dry weight (Winkler unpublished).

The photosynthetic response of the crustose lichen *Lecidea sciatrapha* to light (Fig. 2a) was very similar to that of the macrolichen *Himantormia lugubris*. At a temperature of -5°C CO_2 uptake was already measured at low irradiance levels (25 µmol m^{-2} s^{-1} PPFD) whereas at +10°C irradiances higher than 200 µmol m^{-2} s^{-1} PPFD were necessary to reach the compensation point. Also light saturation for net photosynthesis at the different temperatures was within the same range as for *Himantormia lugubris*. The optimum temperatures varied markedly with irradiance and shifted from subzero temperatures at PPFD <110µmol m^{-2} s^{-1} to +5°C at >380 µmol m^{-2} s^{-1} PPFD (Fig. 2b). A temperature of +10 °C was already unfavourable for this lichen if light intensity did not exceed 225 µmol m^{-2} s^{-1} PPFD. Dark respiration increased dramatically with temperature which is typical for cold-adapted organisms. Although the dark respiration rate was low at -5°C it was still higher than net photosynthetic rates at light intensities up to 200 µmol m^{-2} s^{-1} PPFD.

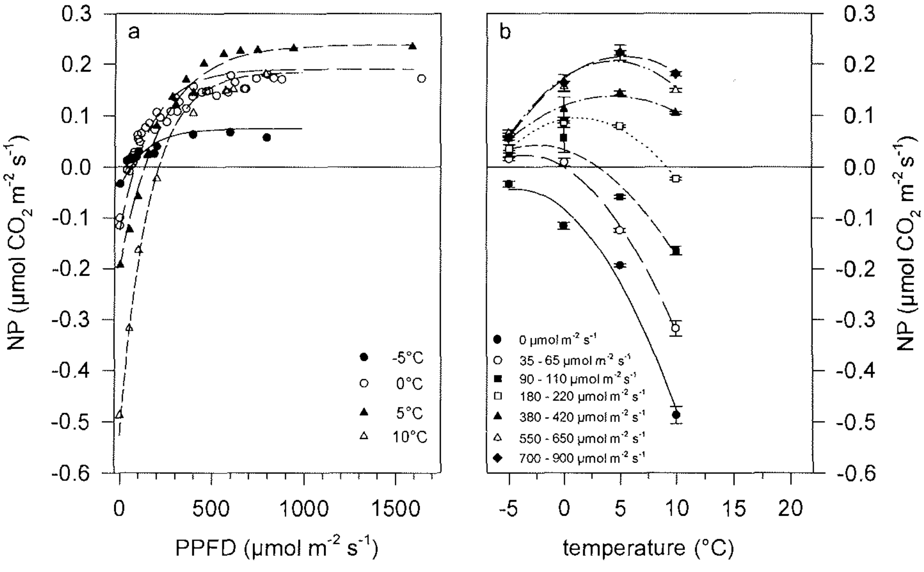

Fig. 2: Light (Fig. 2a) and temperature (Fig. 2b) dependent CO_2 exchange of *Lecidea sciatrapha*. The data were calculated on surface area (Winkler unpublished).

The net photosynthetic rates for *Lecidea sciatrapha* were within the same range as measured *in situ* by KAPPEN et al. (1990). *Himantormia lugubris* reached maximal rates of about 0.8 µmol CO_2 kg DW^{-1} s^{-1} at +10°C and full light. This is similar to that measured by HARRISON & ROTHERY (1988) for *Usnea aurantiaco-atra*.

Our CO_2 exchange measurements indicate that these lichens are well adapted to the prevailing temperatures in the maritime Antarctic. Net photosynthesis in both, *Himantormia lugubris* and *Lecidea sciatrapha,* is possible at temperatures below -5°C. Nevertheless, *Lecidea sciatrapha* seems to be more adapted to cooler conditions. Optimum temperatures were lower (-3°C to +5°C) than for *Himantormia lugubris* (+3°C to +8°C) and even at maximum irradiances the upper threshold value for net photosynthesis of *Lecidea sciatrapha* is supposed to be below +18°C, whereas CO_2 exchange of *Himantormia lugubris* was still positive at +20°C at light intensities higher than 370 μmol m^{-2} s^{-1} PPFD. This may be of ecological relevance because under daytime conditions heating of these blackish thalli is stronger than in other lichens in the same habitat. As a consequence of a prolonged snow cover in the depressions *Lecidea sciatrapha* generally was supposed to be well adapted to low irradiances. This could be confirmed by these measurements. Light compensation points at -5°C and 0°C were between 25 and 50 μmol m^{-2} s^{-1} PPFD which can be reached even if the lichen thallus is covered by snow (KAPPEN & BREUER 1991, KAPPEN et al. 1995). The results of these first experiments will be completed by further CO_2 exchange measurements under controlled conditions and with thalli naturally moistened by snow.

References:

HARRISON, P.M. & ROTHERY, P. (1988): Net CO_2 exchange in relation to thallus moisture and temperature in two fruticose lichens *Usnea antarctica* and *Usnea aurantiaco-atra* from the maritime Antarctic. Polarforschung 58: 171-179.

KAPPEN, L. (1989): Field measurements of carbon dioxide exchange of the Antarctic lichen *Usnea sphacelata* in the frozen state. Antarctic Science 1: 31-34.

KAPPEN, L. (1993a): Lichens in the Antarctic region. In: Friedmann, E.I. (ed.): Antarctic Microbiology. Wiley-Liss, New York: 433-490.

KAPPEN, L. (1993b): Plant activity under snow and ice, with particular reference to lichens. Arctic 46: 297-302.

KAPPEN, L. & BREUER, M. (1991): Ecological and physiological investigations in continental Antarctic cryptogams. II. Moisture relations and photosynthesis of lichens near Casey Station, Wilkes Land. Antarctic Science 3: 273-278.

KAPPEN, L.; MEYER, M.; BÖLTER, M. (1990): Ecological and physiological investigations in continental Antarctic cryptogams. I. Vegetation pattern and its relation to snow cover on a hill near Casey Station, Wilkes Land. Flora 184:209-220.

KAPPEN, L.; SCHROETER, B.; SANCHO, L.G. (1990): Carbon dioxide exchange of Antarctic crustose lichens in situ measured with a CO_2/H_2O porometer. Oecologia 82: 311-316.

KAPPEN, L.; SOMMERKORN, M.; SCHROETER, B. (1995): Carbon aquisition and water relations of lichens in polar regions - potentials and limitations. Lichenologist 27: 531-545.

KAPPEN, L.; SCHROETER, B.; HESTMARK, G.; WINKLER, J.B. (1996): Field measurements of Umbilicarious lichens in winter. Botanica Acta 109: 292-298.

Kappen, L.; Schroeter, B.; Green, T.G.A.; Seppelt, R.D. (1998): Microclimatic conditions, meltwater moistening, and the distributional pattern of *Buelllia frigida* on rocks in a southern continental Antarctic habitat. Polar Biology 19: 101-106.

Lange, O. L. & Metzner, H. (1965): Lichtabhängiger Kohlenstoff-Einbau in Flechten bei tiefen Temperaturen. Naturwissenschaften 52: 191.

Schroeter, B. & Scheidegger, C. (1995): Water relations in lichens at subzero temperatures: Structural changes and carbon dioxide exchange in the lichen *Umbilicaria aprina* from continental Antarctica. New Phytologist 131: 273-285.

Schroeter, B.; Green, T.G.A.; Kappen, L.; Seppelt, R.D. (1994): Carbon dioxide exchange at subzero temperatures. Field measurements on *Umbilicaria aprina* in Antarctica. Cryptogamic Botany 4: 233-241.

Schroeter, B.; Olech, M.; Kappen, L.; Heitland, W. (1995): Ecophysiological investigations of *Usnea antarctica* in the maritime Antarctic. I. Annual microclimatic conditions and potential primary production. Antarctic Science 7: 251-260.

Selkirk, P.M. & Seppelt, R.D. (1987): Species distribution within a moss bed in Greater Antarctica. Symp. Biol. Hung. 35: 279-284.

Smith, R.I.L. (1990a): Signy Island as a paradigm of biological and environmental change in Antarctic terrestrial ecosystems. In: Kerry, K.R. & Hempel, G. (eds.): Antarctic Ecosystems. Ecological change and conservation. Springer-Verlag, Berlin, Heidelberg: 32-50.

Smith, R.I.L. (1990b): Plant community dynamics in Wilkes Land, Antarctica. Proc. NIPR Symp. Polar Biology 3: 229-244.

Photosynthetic light requirements of Antarctic macroalgae in relation to their depth zonation

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Antarctic marine macroalgae occur predominantly in subtidal habitats. In SCUBA diving studies macroalgae were found attached at depths exceeding 40 m (DeLaca and Lipps 1976) and dredged material has been collected from depths down to 700 m (Zaneveld 1966, Zielinski 1990). Beside the various descriptive surveys, some studies have been made on the causes of zonation of Antarctic seaweeds. Ice abrasion, substrate characteristics, competition (Klöser et al. 1996) and herbivory (Iken 1996) have been claimed to be key factors determining distribution patterns. However, macroalgae must have also metabolic pre-requisites, which primarily set their depth distribution limits. In this respect, the upper distribution limit is apparently determined by the capability for dynamic photoinhibition, a process by which excessively absorbed photosynthetically active radiation is dissipated harmless as heat (Hanelt et al. 1994, Hanelt 1996, Bischof et al. 1998). For the lower distribution limit the low light requirements for photosynthesis and growth are of primary importance. Investigations using culture material revealed that in Antarctic algae light saturation and compensation points of photosynthesis and growth are located at very low irradiances (Wiencke 1990a,b, Wiencke and Fischer 1990, Wiencke et al. 1993). Extrapolating these results to the underwater light conditions in Potter Cove (King George Island), Klöser et al. (1993) predicted a depth close to 40 m (2 % of surface irradiance in spring) as lower distribution limit.

In the present report we give a general characterisation of the underwater light conditions and summarize the results obtained in a study on the photosynthetic characteristics of 36 macroalgal species common to shallow waters of King George Island (Weykam et al. 1996). Moreover, we report about results obtained by use of a combination of *in situ* irradiance measurements and of photosynthetic performance of algae collected from different depths in the field (Gómez et al. 1997). The latter study supports the hypothesis that the lower depth limit of Antarctic macroalgae is directly related to their photosynthetic characteristics.

Underwater light climate and macroalgal distribution patterns

Incident irradiance on King George Island is extremely variable depending on the weather conditions (Klöser et al. 1993). During a cloudy day irradiance impinging on the surface is up to 3 times lower compared to a sunny day (Gómez et al. 1997). On the other hand, light suffers attenuation along the water column, a general phenomenon which also depends on seasonally varying physico-chemical (ice cover, input of melt water) or biological (development of phytoplankton blooms) conditions (Klöser et al. 1993). In general, during spring, water transparency is higher than in summer: for example, in November, the 2 % surface irradiance level goes down to 25 m depth, whereas in February, it does not exceed 5 m (Klöser et al. 1993). However, at sites characterized by very clear waters and during high surface irradiances in spring (close to 1500 µmol photons m^{-2} s^{-1}), light can penetrate to depths greater than 40 m (**Fig. 1**, Gómez et al. 1997). Under these conditions, light does not limit photosynthesis over a wide range of depths.

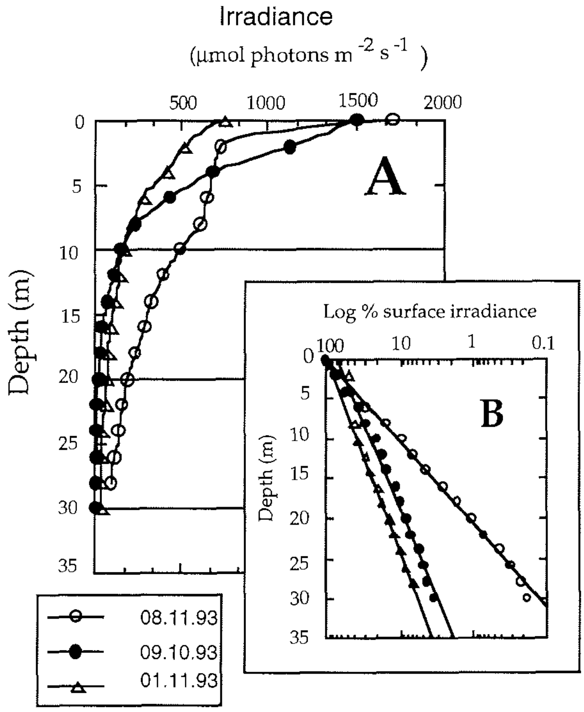

Fig. 1. A) Vertical profiles of irradiance (Photosynthetically Active Radiation, PAR) measured at Potter Cove on 3 different days during spring 1993. B) Light penetration expressed as percentage of surface irradiance.

In the outer Potter Cove (King George Island), 4 main zones can be differentiated: the intertidal zone dominated by annual and pseudoperennial species, the upper sublittoral zone with intense wave action and dominated by *Desmarestia menziesii* and *Ascoseira mirabilis*, the middle sublittoral zone subjected to moderate water disturbance characterized by abundant forests of *Desmarestia anceps* and finally a deep water fringe dominated by *Himantothallus grandifolius* (Klöser et al. 1996). Other species, especially Rhodophytes occupy gaps between the large brown algae at depths between 5 and 20 m. In locations with favourable light conditions and low competition, no limitation by substrate or herbivory, these species can extend their depth distribution limits below 30 m.

Photosynthetic performance and light requirements for photosynthesis in relation to depth distribution

Examination of the photosynthetic characteristics of 36 species common to King George Island and belonging to the Chlorophyta, Rhodophyta, Phaeophyta and Chrysophyta by Weykam et al. (1996) demonstrated the general shade adaptation of field specimen of Antarctic macroalgae. Most of the studied algae are characterized by high photosynthetic efficiencies (α values) and low initial light saturation points (I_k values, mostly lower than 50 μmol photons m^{-2} s^{-1}). Based on these data it is concluded that Antarctic algae use efficiently low irradiances for photosynthesis thereby confirming previous studies carried out using culture material (Thomas and Wiencke 1991, Wiencke et al. 1993).

Further studies gave no evidence for a differential depth dependent photoacclimation (Gómez 1997). In particular, laboratory measurements of O_2 evolution using algae collected at 10, 20 and 30 m indicate that the brown algal species *Himantothallus grandifolius* and *Desmarestia anceps*, and the red algal species *Palmaria decipiens*, *Gigartina skottsbergii* and *Kallymenia antarctica* only show erratic differences in photosynthetic characteristics among plants from different depths. For example, in *D. anceps* the highest P_{max} and α values were measured in plants collected at 20 and 30 m depth. In contrast, in *P. decipiens* no differences in these parameters were found. These findings suggest that the studied species are potentially able to maintain optimal photosynthetic rates over a wide range of depths. The small determined changes in pigment content and C:N ratios also support the absence of photoacclimation as plants achieve a similar light absorption capacity and allocation of organic matter (Gómez et al. 1997). On the other hand, the low I_c and I_k values determined indicate that photosynthesis is not limited over a wide range of depths during the prevailing favourable light conditions in the Antarctic spring and early summer.

Light climate and metabolic carbon balance

Low light requirements for photosynthesis allow sufficient production for a long time of the day. Using data on daily changes of *in situ* irradiance and P-I derived parameters such as P_{max}, dark respiration, I_c and I_k, it is possible to calculate the daily periods over which C assimilation exceeds C losses due to respiratory activity at the different water depths. This metabolic C balance is regarded to determine the lower distribution limit of algae. Due to the low I_k values algae are exposed during spring-summer for periods $\geq$ 12 h per day at $\leq$ 20 m depths to irradiances above saturation (H_{sat}). Under these conditions species such as *Palmaria decipiens* or *Desmarestia anceps* achieve positive C balances close to 3 mg C g^{-1} FW d^{-1} (**Fig. 2**). At 30 m depth daily light availability decreases to values close to 7 or 9 h, but C balance is still positive in four species (Gómez et al. 1997). Only in the case of *Desmarestia anceps* from 30 m, a negative C balance was determined, indicating that the alga is at this depth at its lower distribution limit. In contrast, *P. decipiens, Gigartina skottsbergii* and *Kallymenia antarctica* are metabolically able to grow even in

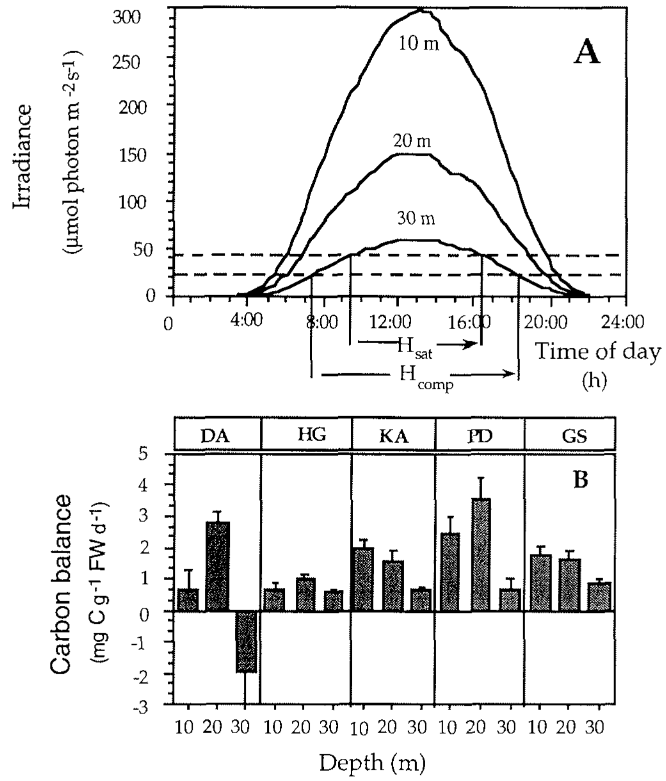

Fig. 2. A) Daily changes of irradiance measured in different depths *in situ* at Potter Cove indicating the times during which photosynthesis is light saturated (H_{sat}) and during which photosynthesis compensates respiration (H_{comp}). B) Daily carbon balance calculated using photosynthesis : respiration ratios, daily light cycles and H_{sat} (See Gómez et al. 1997 for details of calculations; DA= *Desmarestia menziesii*; HG= *Himantothallus grandifolius*; KA= *Kallymenia antarctica*; PD= *Palmaria decipiens*; GS= *Gigartina skottsbergii*).

deeper waters. However, other factors such as competitive exclusion or substrate limitation can impair colonization at these depths.

In conclusion, Antarctic macroalgae show a remarkable adaptation to low light conditions. High α values and low I_k and I_c points for photosynthesis are major factors determining the success of Antarctic algae to grow under seasonally changing Antarctic light conditions (Wiencke 1990a,b, Gómez et al. 1995, 1998) and at great depths. On the other hand there is no obvious acclimation to the light conditions in different depths. This is reflected by similar photosynthetic rates and pigment contents, and low light requirements for photosynthesis over a long vertical gradient. However, data on net daily C assimilation relative to daily C losses due to respiration show that some algae are unable to inhabit depths greater than 30 m. A critical daylight period during which algae are exposed to light saturating irradiances appears as a key factor setting the lower distribution limits of these species.

References

Bischof, K., Hanelt, D. and Wiencke, C. (1998): UV radiation can affect depth distribution of Antarctic macroalgae. Mar. Biol. (in press).

DeLaca, T.E. and Lipps, J.H. (1976). Shallow-water marine associations, Antarctic Peninsula. Antarctic J. U.S. 11:12-20.

Gómez, I. (1997). Life strategy and ecophysiology of Antarctic macroalgae. Reports Polar Res. 238: 1-99.

Gómez, I., Wiencke, C. and Weykam, G. (1995). Seasonal photosynthetic characteristics of *Ascoseira mirabilis* (Ascoseirales, Phaeophyceae) from King George Island, Antarctica. Mar. Biol. 123: 167-172.

Gómez, I., Weykam, G. and Wiencke, C. (1998). Seasonal photosynthetic metabolism and major organic compounds in the marine brown alga *Desmarestia menziesii* from King George Island (Antarctica). Aquatic Bot. (In press).

Gómez, I., Weykam, G., Klöser, H. and Wiencke, C. (1997). Photosynthetic light requirements, metabolic carbon balance and zonation of sublittoral macroalgae from King George Island (Antarctica). Mar. Ecol. Prog. Ser. 148: 281-293.

Hanelt, D. (1996). Photoinhibition of photosynthesis in marine macroalgae. Scientia Mar. 60 (Suppl. 1): 243-248

Hanelt, D., Jaramillo, I.M., Nultsch, W., Senger, S, and Westermeier, R. (1994). Photoinhibition as regulative mechanism of photosynthesis in marine algae of Antarctica. Ser. Cient. INACH 44: 57-77.

Iken, K. (1996). Trophische Beziehungen zwischen Makroalgen und Herbivoren in der Potter Cove (King George-Insel, Antarktis). Reports Polar Res. 201: 1-206.

Klöser, H., Ferreyra, G., Schloss, I., Mercuri, G., Laturnus, F. and Curtosi, A. (1993). Seasonal variations of algal growth conditions in sheltered Antarctic bays: the example of Potter Cove (King George Island, South Shetlands). Polar Biol. 14:11-16.

Klöser, H., Quartino, M.L. and Wiencke, C. (1996). Distribution of macroalgae and macroalgal communities in gradients of physical conditions in Potter Cove, King George Island. Hydrobiologia 333: 1-17.

Thomas, D.N. and Wiencke, C. (1991). Photosynthesis, dark respiration and light independent carbon fixation of the endemic Antarctic macroalgae. Polar Biol. 11: 329-337.

Weykam, G., Gómez, I., Wiencke, C., Iken, K. and Klöser, H. (1996). Photosynthetic characteristics and C/N ratios of macroalgae from King George Island (Antarctica). J. Exp. Mar. Biol. Ecol. 204: 1-22.

Wiencke, C. (1990a). Seasonality of brown macroalgae from Antarctica - a long-term culture study under fluctuating Antarctic daylengths. Polar Biol. 10: 589-600.

Wiencke, C. (1990b). Seasonality of red and green macroalgae from Antarctica- a long-term culture study under fluctuating Antarctic daylengths. Polar Biol. 10: 601-607.

Wiencke, C. and Fischer, G. (1990). Growth and stable carbon isotope composition of cold-water macroalgae in relation to light and temperature. Mar. Ecol. Prog. Ser: 65:283-292.

Wiencke, C, Rahmel, J., Karsten, U., Weykam, G. and Kirst, G.O. (1993). Photosynthesis of marine macroalgae from Antarctica: light and temperature requirements. Bot. Acta. 106: 78-87.

Zaneveld, J.S. (1966). Vertical zonation of Antarctic and Subantarctic benthic marine algae. Antarctic J. U.S. 1: 211-213.

Zielinski, K. (1990) Bottom macroalgae of the Admiralty Bay (King George Island, Antarctica). Pol. Polar Res. 11: 95-131.

Speciation of Volatile Organohalogen Compounds Released by Antarctic Macroalgae

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The discovery of the formation of an ozone hole over Antarctica during the last decade led to several studies on the reasons of stratospheric ozone destruction and its effects on the global environment. It has been found that photochemically formed halogen radicals (X = mainly chloro- and bromoradicals) decompose ozone (O_3) in the lower stratosphere of the South polar region each year at sunrise in spring (Solomon 1990) by a catalytic process (1-3).

$$\begin{array}{llcl} (1) & X + O_3 & \rightarrow & O_2 + XO \\ (2) & XO + O & \rightarrow & X + O_2 \\ \hline (3) & O + O_3 & \rightarrow & 2O_2 \end{array}$$

As sources of these halogens, chloro- and chlorofluorohydrocarbons (*CFC*s) released by human activities have been identified. The widespread use of these anthropogenic halocarbons as coolants, propellants, agents for fire extinguishers, fuel additives and solvents caused a high input into the atmosphere. Although several industrial nations have stopped the production and use of these compounds by 1996 (Montreal protocol), it will take until mid of the next century to reduce concentrations to the level before the ozone hole developed due to a very long atmospheric lifetime of most of the anthropogenic halocarbons.

Beside this anthropogenic input of volatile halocarbons into the atmosphere also a biogenic flux exists. Whereas the anthropogenic input mainly consists of chlorinated compounds, the biogenic part is dominated by brominated and iodinated hydrocarbons. Especially brominated compounds have received considerable interest recently. Like the *CFC*s, some bromocarbons, *e.g.* methyl bromide, are stabile enough to reach the lower stratosphere before they were photolytically decomposed, and serve as a halogen source. However, bromine is about 50 times more effective in destroying stratospheric ozone than chlorine, and, therefore, would have a much higher impact on the destruction of the ozone layer (Butler 1995).

Contrary to the well-known release of anthropogenic volatile halocarbons from industrial production, data on the biogenic input are scarce because their sources have not been fully explored yet. The oceans were reported as an important source for biogenic halocarbons (Singh *et al.* 1983), but also terrestrial sources like forest soil may have to be considered as a contributor to the halocarbon flux (Laturnus *et al.* 1995). In the oceans, marine macroalgae were identified to release volatile halocarbons (Gschwend *et al.* 1985, Laturnus 1996). However, as macroalgae are restricted to coastal areas, they may not only be responsible for the halocarbon concentrations detected in the open oceans. Recently, the release of volatile halocarbons by unialgal cultures of marine phytoplankton were reported (Tokarcsyk and Moore 1994). However, field data from the open oceans supporting the implication of phytoplankton in producing volatile halocarbons are still missing. Thus, an extrapolation from these controlled culture experiments to the marine environment cannot be done yet.

Table 1. Various volatile halogenated hydrocarbons detected from several macroalgal species from King George Island, Antarctica. Values are the average release rates and variation of the rates determined from the different algal species.

compound detected	formula	release rate [pmol g^{-1} wet algal weight day^{-1}] average	range
methyl chloride	CH_3Cl	35	0 - 2.8*10^3
methyl bromide	CH_3Br	2	0 - 67
bromochloromethane	CH_2BrCl	9.2	0 - 85
dibromomethane	CH_2Br_2	90	0 - 693
bromodichloromethane	$CHBrCl_2$	23	0 - 145
dibromochloromethane	$CHBr_2Cl$	48	0 - 600
bromoform	$CHBr_3$	1.3*10^3	0 - 15.5*10^3
bromoethane	C_2H_5Br	719	0 - 3.5*10^3
1,2-dibromoethane	1,2-$C_2H_4Br_2$	41	0 - 266
methyl iodide	CH_3I	1.7	0 - 63
chloroiodomethane	CH_2ClI	3.8	0 - 39
diiodomethane	CH_2I_2	68	0 - 183
iodoethane	C_2H_5I	6	0 - 36
1-iodopropane	1-C_3H_7I	0.48	0.03 - 1.4
2-iodopropane	2-C_3H_7I	1.25	0.03 - 11
1-chloro-2-iodopropane	1,3-C_3H_6ClI	not quantified	
1-iodobutane	1-n-C_4H_9I	0.27	0 - 0.58
2-iodobutane	2-n-C_4H_9I	0.08	0 - 0.20
1-iso-iodobutane	1-iso-C_4H_9I	0.07	0 - 0.25

Attention has been focused on the halocarbon release by macroalgae located in the polar regions. Especially in Antarctica, where stratospheric ozone depletion reached high levels, macroalgae occur down to considerable depths (> 30m) along thousands of kilometers of coastlines in the Antarctic peninsula region (Klöser et al. 1993, 1996), and would have a much higher influence on the impact of halocarbons into the atmosphere of the South polar region, than algae from temperate or subtropic regions.

Since 1991, several species of red, green and brown Antarctic macroalgae collected at King George Island, South Shetland, were investigated in field and culture experiments for the release of volatile halogenated compounds. A wide range of brominated, chlorinated and iodinated compounds from methanes to butanes were identified and their release rates by Antarctic macroalgae have been determined (Table 1).

Interesting is that many halocarbons, *e.g.* methyl bromide (used for soil fumigation) or 1,2-dibromoethane (used as gasoline additive), which were believed to have an anthropogenic origin only, are also formed biogenically. Among the compounds found, bromoform dominates the halocarbon release due to its up to 20 -30 fold higher release rates compared to the release rates of other main compounds like dibromomethane and dibromochloromethane (Table 2). The release of volatile halocarbons by Antarctic macroalgae occurred predominatly by brown and green algal species, whereas red algal species showed only low release (Laturnus et al. 1996). As reported also for temperate algal species (Nightingale et al. 1995), red macroalgae seem to play a minor role with regards to the halocarbon input into the global environment. However, since the first investigations of halocarbon formation by marine macroalgae, the most manifold assortment of halogenated organic compounds has been found in the extracts of red macroalgae (Fenical, 1975). Thus, red algae were regarded as an abundant source for halocarbons. Apparently, they can synthesis a wide range of halogenated compounds, but as contributor to the input of volatile halocarbon into the Antarctic environment, they may be of minor importance.

From the average release rates of brominated and iodinated compounds shown in Table 1, and calculating with a total algal biomass of $6.0*10^{13}$g (after De Vooys 1979), and assuming a 100% transfer of the compounds from the oceans into the atmosphere, an atmospheric input can be calculated for iodine and bromine from macroalgae sources of around $4.2*10^{7}$ g iodine year^{-1} originated to 80% from diiodomethane, and $9.8*10^{9}$ g bromine year^{-1} originated to 73% from bromoform. However, compared to temperate macroalgae, Antarctic macroalgae showed *e.g.* 10 to 50-fold lower release rates for methyl halides and 2 to 5-fold lower release rates for bromoform (Laturnus et al. 1998a). Therefore, estimations of the global input of iodine and bromine calculated only from release rates of Antarctic macroalgae may lead to values lower than actually occurred. Furthermore, as the yearly input of iodine and bromine from the oceans into the atmosphere is estimated to 10^{12} g iodine (Miyake and Tsunogai 1963) and 10^{10} - 10^{12} g bromine (Goodwin et al. 1998), respectively, macroalgae may not be the only source for volatile halocarbons. Other yet so far unknown sources can exist.

Table 2. Main released volatile halocarbons from selected species of Antarctic macroalgae

algae species	main compounds	release rate [pmol g^{-1} waw d^{-1}]
Phaeophyta (brown algae)		
Desmarestia antarctica Moe et Silva	$CHBr_3$	253
Desmarestia anceps Montagne	$CHBr_3$, CH_2Br_2, $CHBr_2Cl$	15491, 693, 599
Desmarestia menziesii J.Agardh	$CHBr_3$, CH_2Br_2, $CHBr_2Cl$	5190, 390, 317
Himantothallus grandifolius (A. et E.S. Gepp) Zinova	$CHBr_3$, CH_2Br_2	952, 144
Cystosphaera jaquinotii (Montagne) Skottsberg	$CHBr_3$, CH_2Br_2, $CHBr_2Cl$	3348, 620, 379
Rhodophyta (red algae)		
Kallymenia antarctica Hariot	$CHBr_3$	179
Plocamium coccineum (Hudson) Lyngbye	$CHBr_3$	226
Gymnogongrus antarcticus Skottsberg	CH_3Cl, CH_3Br	27, 4.1
Gigartina skottsbergii (Bory) Setchell and Gardner	$CHBr_3$, CH_3Cl, CH_2Br_2	277, 30, 29
Iridaea cordata Kützing	$CHBr_3$	106
Palmaria decipiens (Reinsch) Ricker	$CHBr_3$	298
Myriogramme mangini (Gain) Skottsberg	$CHBr_3$, CH_2Br_2	425, 94
Curdiea racovitzae Hariot	$CHBr_3$, $CHBr_2Cl$, CH_2I_2	1254, 1401, 119
Chlorophyta (green algae)		
Enteromorpha bulbosa (Suhr) Montagne	$CHBr_3$, CH_2I_2	219, 40
Enteromorpha compressa (Linné) Greville	$CHBr_3$, CH_3Br	65, 3.7

waw = wet algal weight

For the formation of halocarbons an enzymic controlled mechanism is assumed (Neidleman and Geigert 1986). Haloperoxidases, an enzyme group detected in a wide range of marine and terrestrial organisms, can catalyze the oxidation of halogens in the presence of hydrogen peroxide to form halogenated organic compounds (4).

$$(4)\quad \text{organic matter} + H_2O_2 + H^+ + X^- \rightarrow \text{organic - X}$$
$$(X^- = Cl^-, Br^-, I^-)$$

Metabolic pathways by which volatile halocarbons such as bromoform are synthesized have been discussed by several authors (Fenical 1975, Neidleman and Geigert, 1986). However, the exact formation mechanisms of most of the volatile halogenated C_1 - C_4 hydrocarbons remain unknown. Furthermore, nothing can be said yet about the function of volatile halocarbons in algal life. Fenical (1975) pointed out that they may be a chemical defense against microorganisms or herbivores. However, it cannot be excluded that these small molecules have no particular function, and, maybe, are only decomposition products in algal metabolism.

Antarctic macroalgae have been found to produce and release several volatile halogenated organic compounds and are an important biogenic source of these compounds in the environment. Although they apparently play a minor role only in the global input of volatile halocarbons, they are located in an area known for their high destruction of the stratospheric ozone layer. This makes these organisms a considerable source for halides in the Antarctic environment. Recently, during the investigation of the dependence of the halocarbon release from varying light conditions, it was found that Antarctic algae exhibit higher halocarbon release rates at lower light intensities and in the dark (Laturnus *et al.* 1998b), *i.e.* at conditions occurring during the Antarctic winter. In addition, higher release rates were often found for the release of monohalogenated methanes at short photoperiods. This may be important for the contribution of Antarctic macroalgae to the atmospheric chemistry in the south polar region. A higher release of volatile halocarbons during the winter may support the build up of high concentrations of these compounds until sunrise and sea ice break up in spring. Therefore, the contribution of naturally produced volatile halocarbons to the destruction of the ozone layer, which appeared over Antarctica in spring after sun rising (Solomon, 1990), would be much higher than generally assumed.

References

Butler J.H. (1995). Methyl bromide under scrutiny. Nature, 376: 469.

De Vooys C.G.N. (1979). Primary production in aquatic environments. In: Bolin, B. (ed) The gobal carbon cycle. Wiley&Sons, Chichester, p. 259-292.

Fenical W. (1975). Halogenation in the Rhodophyta - a review. J. Phycol., 11: 245-259.

Gschwend P.M., MacFarlane J.K. and Newman K.A. (1985). Volatile halogenated organic compounds released to seawater from temperate marine macroalgae. Science, 227: 1033-1035.

Goodwin K.D., North W.J. and Lidstrom M.E. (1998). Production of bromoform and dibromomethane by giant kelp: factors affecting release and comparison to anthropogenic bromine sources. Limnol. Oceanogr., (in press).

Klöser H., Ferreyra G., Schloss I., Mercuri G., Laturnus F. and Curtosi T. (1993). Seasonal variation of algal growth conditions in sheltered Antarctic bays: the example of Potter Cove (King George Island, South Shetlands). J. Mar. Syst., 4: 289-301.

Klöser H., Quartino M.L. and Wiencke C. (1996) Depth distribution of macroalgae and macroalgal communities in gradients of physical conditons in Potter Cove, King George Island, Antarctica. Hydrobiologica, 333: 1-17.

Laturnus F., Mehrtens G. and Grøn C. (1995). Haloperoxidase-like activity in spruce forest soil - a source of volatile halogenated organic compounds? Chemosphere, 31: 3709-3719.

Laturnus F., Klöser H. and Wiencke C. (1996). Antarctic macroalgae - sources of volatile halogenated organic compounds. Mar. Environ. Res., 41: 169-181.

Laturnus F. (1996). Volatile halocarbons released from Arctic macroalgae. Mar. Chem., 55: 359-366.

Laturnus F., Adams F.C. and Wiencke C. (1998a) Methyl halides from Antarctic macroalgae. Geophys. Res. Lett., 25: 773-776.

Laturnus F., Wiencke C. and Adams F.C. (1998b). Influence of light conditions on the release of volatile halocarbons by Antarctic macroalgae. Mar. Environ. Res., (in press).

Miyake Y. and Tsunogai S. (1963). Evaporation of iodine from the ocean. J. Geophys. Res., 68: 3989-3993.

Neidleman S.L. and Geigert J. (1986). Biohalogenation - principles, basis roles and applications. Ellis Horwood Series in Organic Chemistry, Ellis Horwood, Chichester, England.

Nightingale P.D., Malin G. and Liss P.S. (1995). Production of chloroform and other low-molecular-weight halocarbons by some species of macroalgae. Limnol. Oceanogr., 40:680-689.

Singh H.B., Salas L.J. and Stiles R.E. (1983). Methyl halides in and over the eastern Pacific (40 °N - 32 °S). J. Geophys. Res., 88: 3684-3690.

Solomon S. (1990). Progress towards a quantitive understanding of Antarctic ozone depletion. Nature, 347: 347-354.

Tokarczyk R. and Moore R.M. (1994). Production of volatile organohalogens by phytoplankton cultures. Geophys. Res. Lett., 21: 285-288.

PROTEASE-PRODUCING PSYCHROTROPHIC ANTARCTIC BACTERIA

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Introduction

According to previous reports, it is known that psychrotrophic bacteria –able to divide at 0°C and grow optimally at temperatures around 20-25°C- (Morita, 1975) produce several kinds of proteases which differ from one another in optimal pH and temperature. In the Antarctic environment, the bacterial flora is adapted to grow -or survive, at least- at low temperatures, as it is enzyme production and activity. While in permanently cold areas like glaciers, sea waters or sediments there is a psychrophilic dominance, psychrotrophic bacteria constitute most of the isolates obtained from those habitats which experience seasonal variation in temperature, like soils, marine coasts, streams or shallow waters present in subantarctic areas. The extracellular protease production is broadly distributed among the cold adapted bacteria present in this environment, and these proteolytic microorganisms play an important ecological role in the nitrogen cycle.

Besides the academic interest in the knowledge of the basic biochemical aspects, there is a practical interest in these enzymes because proteases account for nearly 60% of the industrial enzyme market. The alkaline proteases, for example, are used currently in washing products, leather tanning and the food industry. As the optimum temperature of the majority of the enzymes used at the present is around 55°C, there is a general interest to find proteases with lower optimum temperature, which would result in a considerable energy economy.

The aim of our research was to isolate psychrotrophic bacteria from the Antarctic environment in order to select those capable of producing extracellular proteases.

Methodology

Sampling area: The samples were taken during Argentine summer Antarctic Research Expeditions 1989/90 and 1991/92 near Jubany scientific station (62° 14'S, 58°40'W) on King George Island (South Shetland Islands). Samples were collected from soil, fresh and marine waters, sea sediments and remains of organic matter of animal and vegetal origin.

Screening and isolation of psychrotrophic bacterial strains: Samples from soil and organic matter were placed in a screw-capped bottle containing 5 g of sterile sand and 15 ml of sterile diluent (1 g l^{-1} of peptone solution) and shaken manually for 15 min. After shaking, serial decimal dilutions were prepared in the same diluent and 0.1 ml of such dilutions were spread on the surface of nutrient agar plates (Merck) for counting of total heterotrophic bacteria.

Proteolytic bacteria was screened by spreading 0.1 ml of dilutions on 2.5% w v^{-1} skim milk, 0.4% w v^{-1} yeast extract agar plates pH 7. Proteolytic activity was detected as clear zones around the colony.
Samples from marine origin were processed in the same way but the diluent solution and media were prepared using 75% v v^{-1} of sea water. Plates were incubated at 10-13°C (summers 1989/90 and 1991/92), 20°C (1994/95) and 4-6°C (1995/96). Different proteolytic colonies were isolated and purified by re-streaking twice.

Characterization of bacterial strains: Selected proteolytic bacteria were Gram stained and shape and size of the cells were examined under the light microscope. Their mobility was investigated in hanging drops. The color of the colonies was observed on nutrient agar plates (Merck). Catalase, cytochrome oxidase activity and aerobic and anaerobic utilization of glucose (Hugh-Leiffson media) were also tested. Some strains were identified at genus level using the determinative schemes of Shewan et al. (1960 a,b) and Shewan (1971) for Gram-negative strains and of Molin et al. (1983) for Gram-positive strains.

Submerged culture conditions: Growth experiments were performed with nutrient broth (Oxoid CM1) supplemented with 0.3 g l^{-1} $CaCl_2$, pH 8. For marine strains the medium was rehydrated with 100% v v^{-1} artificial sea water (Lyman and Fleming, 1970). Experiments were carried out in 300 ml Erlenmeyer flasks with 60 ml of nutrient broth and incubated at 20°C in a rotatory shaker at 240 rpm. Inocula were grown in the same medium, adjusted to an optical density of 0.100 and added to nutrient broth at 1% v v^{-1} proportion. Samples were taken after 24, 48 and 72 hours of incubation and used to determine growth, pH and proteolytic activity. All the experiments were performed in duplicate.

Estimation of growth: Growth was monitored by measuring the optical density (OD) of the samples in a UV-visible spectrophotometer (Metrolab 2500) at 580 nm.

Protease assay: Proteolytic activity was measured by digestion of azocasein (Sigma). An appropriate dilution of culture supernatant (400 µl) was incubated with 400 µl of 1% w v^{-1} azocasein in 0.1 mol l^{-1} Tris; 0.5 mmol l^{-1} $CaCl_22H_2O$ buffer (pH 8.0) at 20°C for 30 min. The reaction was stopped by adding 800 µl 5% w v^{-1} trichloracetic acid. After centrifugation of reaction mixture, absorbance of the supernatant was measured at 340 nm. Samples were assayed in duplicate and the activity was expressed in relative enzymatic units (EU). One EU was defined as the amount of enzyme that produces an increase of 0.100 in A_{340} under the assay conditions.

Effect of pH and temperature on activity of proteases: These effects were determined by using the protease assay described above. Determination of the pH optimum was performed at 20°C with the following buffer systems (0.1 M each): KH_2PO_4-Na_2HPO_4 (pH 5-7); Tris-HCl (pH 8-9) and Na_2HPO_4-NaOH (pH 10-12). For the determination of the optimum temperature, the reaction was carried out at various temperatures and at pH 8.0.

Polyacrilamide gels: Extracellular protease profiles were analyzed by SDS-PAGE minigels containing gelatin as copolymerized substrate (Heussen and Dowdle, 1980). Proteolytic activity was evident as bands depleted of gelatin.

Results

The total heterotrophic bacterial counts from similar samples taken during the summers 1994/95 (highest incubation temperature, 20°C) and 1995/96 (lowest incubation temperature, 4-6°C) were similar when water and sediments were tested, and different for soil and organic matter samples (Tab.1). As psychrotrophs grow faster at 20°C than at 4°C, the higher counts obtained with terestrial samples when the temperature of incubation was 20°C might be related to the predominance of this type of microorganisms in areas exposed to a wide seasonal variation in temperature. Also the presence of spore-forming bacteria was observed when incubated at 20°C and they could not be isolated at 4°C, probably because this temperature was not suitable for the germinations of the spores.

On the basis of a clear zone in skim milk agar, 123 proteolytic strains were selected (20 from the summer of 1989/90; 14 from 1991/92; 40 from 1994/95 and 49 from 1995/96). We considered different "strains" those isolates that either originated from various sites, or differed in appearance (form, shape, color of the colonies) when originating from one single site. All the strains were capable of growth at 0°C but had an optimum temperature higher than 15°C, corresponding to psychrotrophic microorganisms (Morita, 1975). The majority of them were Gram-negative rods. Mobile strains with cytochrome oxidase activity dominated. Almost all the strains had catalase activity and none of them were glucose fermenters. Morphological characteristics and biochemical tests made it possible to classify only a few of the strains. Approximately 80% proved to be *Pseudomonas* spp., other Gram-negative genera (*Flavobacterium*, *Moraxella*, *Vibrio* and *Acinetobacter*) being poorly represented.

Table 1: Total heterotrophic bacterial counts in nutrient agar plates, from different samples taken during summer Antarctic Research Expeditions 1994/95 (incubation at 20°C) and 1995/96 (incubation at 4-6°C).
(*): cultivable heterotrophic bacteria colony counts on nutrient agar by gram of wet sample
(#): remains of organic matter
nd: not determined

Sample	Origin	pH	CFU g^{-1} (*)	
			Incubation at 20°C	*Incubation at 4-6°C*
OM(#)	fresh water stream	8.0	nd	9.0E+04
	lichen-rhizosphera	5.5	1.8E+06	1.0E+05
	moss-rhizosphera	6.0	4.3E+06	3.0E+04
	dead elephant seal	nd	4.0E+06	3.5E+04
	moss-Ballve refuge, Mariana Cove	nd	1.3E+06	nd
WATER	Fourcade glacier	6.0	nd	9.6E+02
	Potter Cove	7.8	nd	1.3E+03
SOIL	near Fourcade glacier	nd	2.6E+05	1.0E+04
ALGAE	Potter Cove, coast	7.0	5.0E+05	4.6E+05
SEDIMENT	lagoon near Three Brothers hill	7.2	7.5E+03	1.7E+03
	Potter Cove (5m deep)	7.2	3.0E+03	nd
	Potter Cove (20m deep)	7.4	nd	3.2E+03
	Potter Cove (30m deep)	7.7	nd	2.4E+04

Only two Gram-positive strains could be identified (one *Staphylococcus* sp. and one *Bacillus* sp.), in spite of their known capacity (especially *Bacillus*) to produce and secrete proteases (Keay and Wildi, 1970). The difficulty in trying to identify psychrotrophic bacteria (as well as other extremophiles) is well known, as the identification generally results from a rather quick analysis of lipid, protein patterns or enzyme profiles. The true identification of already baptized Antarctic strains would certainly require ribotyping next to multiple analysis of their physiological and biochemical characteristics, and there is no doubt that a lot of them will necessitate the definition of new taxa (Feller et al., 1996).

All the selected strains were cultured in nutrient broth monitoring the evolution of growth and protease production along the incubation time. Some strains showed a protease production kinetic directly associated with growth (Fig. 1.a), while others presented a partially or non-growth associated enzyme production, which started at the early stationary phase of growth (Fig.1.b).

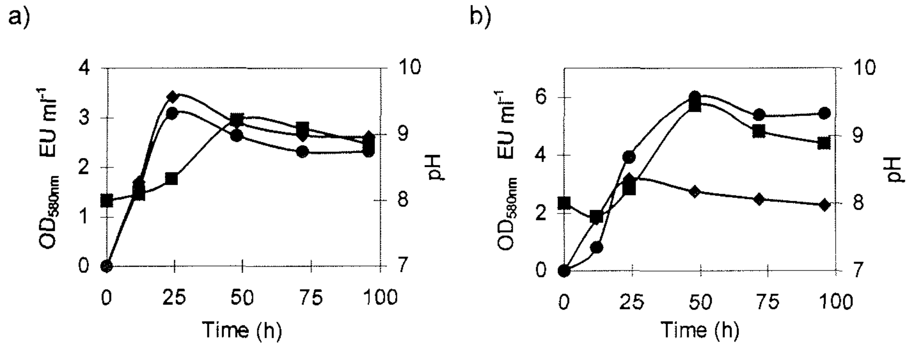

Figure 1: Growth and protease production kinetics. (◆) Growth [OD_{580nm}];(●) Proteolytic activity [EU ml^{-1}]; (■) pH. When strains were cultivated in submerged culture, protease production showed two different behaviors: enzyme production was directly associated with growth (a); protease production was not associated with growth (b).

With some strains we failed to detect proteolytic activity (azocasein method) at any time along the culture, thus being discarded. After separation of cells by centrifugation, the proteases present in culture broth supernatants were partially characterized. Twenty-five strains were selected on the basis of their optimum temperature for substrate utilization and of the percentage of relative activity measured at 20°C with respect to the activity measured at optimum temperature (Tab.2). All selected proteases were classified as neutral proteases, regarding the optimum pH for activity (Tab.3).

Developing of proteolytic activity of culture supernatants on SDS-PAGE with gelatin as a copolymerized substrate gave mainly multiple bands profiles (Fig.2). Among the 25 protease-containing supernatants with the lowest temperature optimum found (40°C), only 8 developed a single proteolytic band, and were selected as the most interesting proteases for performing further studies.

Table 2: Optimum temperature (OT) and RA(%) -relative activity measured at 20°C with respect to the activity measured at optimum temperature- of crude proteases from 25 Antarctic psychrotrophic strains.

Strain	OT(°C)	RA(%)	Strain	OT(°C)	RA(%)	Strain	OT(°C)	RA(%)
Ele-2	40	34	P95-8	45	17	P96-20	45	21
Ele-3	40	19	P95-9	45	22	P96-23	45	19
TCN-2	45	13	P95-16	45	20	P96-27	45	14
GUD-5	50	12	P95-17	45	26	P96-28	45	9
GUD-8	50	17	P95-18	45	29	P96-29	40	29
ANT-1-1	55	6	P95-19	45	24	P96-33	40	21
ANT-3-1	50	6	P95-20	>50	12	P96-35	40	35
ANT-7-1	55	6	P95-21	>50	25	P96-37	50	22
YOA-3	60	5	P95-24	40	30	P96-38	45	37
814	40	32	P95-27	40	10	P96-39	45	34
PIEL-1	40	29	P95-28	>50	10	P96-41	40	14
91	50	35	P95-29	>50	21	P96-43	40	31
435	50	30	P95-31	>50	27	P96-44	50	26
337	50	9	P95-32	>50	9	P96-45	45	14
273	50	13	P95-33	>50	13	P96-46	45	7
A1	50	6	P95-37	>50	25	P96-47	45	27
Prot-2	50	17	P95-38	>50	15	P96-48	45	21
Prot-4	50	20	P95-39	>50	19	P96-49	40	23
Prot-5	45	18	P95-40	>50	9	P96-50	40	35
Prot-8	40	34	P96-1	45	30	P96-51	40	16
Prot-9	40	13	P96-3	45	28	P96-52	40	22
Prot-10	50	11	P96-4	45	29	P96-53	40	24
Prot-11	40	14	P96-5	40	23	P96-54	40	22
Prot-12	55	7	P96-6	50	11	P96-55	45	40
Prot-14	45	29	P96-7	40	33	P96-56	45	21
P95-1	40	21	P96-12	40	13			
P95-6	40	15	P96-18	40	24	Subtilisin	55	12

Table 3: Optimum pH of crude proteases (optimum temperature of proteases 40°C) from 25 proteolytic Antarctic strains. (*): single proteolytic band developed in gelatin-SDS-PAGE

Strain	pH	Strain	pH
(*)Ele-2	8	P96-18(*)	7 ; 9
Ele-3	8 to 11	P96-29	7 ; 9
Prot-8	8 to 9	P96-33	8
Prot-9(*)	6 to 11	P96-35(*)	7 ; 9
Prot-11(*)	8	P96-41	7 ; 9
814	8 to 9	P96-43	7 ; 9
PIEL-1	8 to 9	P96-49	8
P95-1(*)	7 ; 9	P96-50	9
P95-21(*)	7 ; 9	P96-51	8
P95-24(*)	7 to 10	P96-52	8 ; 10
P96-5	8	P96-53	7 ; 9
P96-7	9	P96-54	9
P96-12	7		

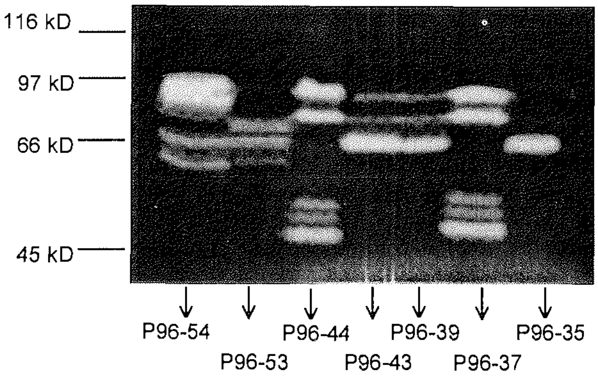

Figure 2: Multiple and single proteolytic band profiles developed in SDS-PAGE with gelatin as a copolymerized substrate.

A summary of the results obtained along the three summers of Antarctic Research Expeditions can be observed in Table 4. We could point the relevance of choosing the proper conditions when designing screening programs. For the selection of proteolytic bacteria in Antarctica, the incubation temperature seems to be an important factor to take into account in order to direct the screening towards the isolation of bacteria producing the desired type of proteases.

Table 4: Effect of using different isolation temperatures on the selection of psychrotrophic Antarctic proteolytic bacteria.

		Summer '94-'95	Summers '88-'89 91-'92	Summer '95-'96
		Isolation at 20°C	*Isolation at 10-13°C*	*Isolation at 4-6°C*
Pigmented strains		40%	15%	22%
Form	*rod-shaped*	87%	97%	88%
	spore-forming	13%	1%	0%
	cocci-shaped	13%	3%	2%
Gram stain	*positive*	40%	6%	14%
	negative	60%	94%	86%
Detection of proteases in submerged culture		53%	73%	67%
Optimum temperature for activity	*40°C*	14%	24%	45%
	45°C	29%	6%	46%
	>50°C	57%	70%	9%
Number of isolated strains		*40*	*34*	*49*

Discussion

Microbiological studies related to Antarctic environments are frequently focused on the role of the bacterial community as a whole in heterotrophic production, the cycling of matter or the activities relating bacterial flora to the trophic dynamics of food webs. However, the majority of these studies do not discriminate between the different taxonomic groups that constitute the total flora responsible for one particular activity. Nevertheless, when a global analysis of the bacterial flora of a particular Antarctic environment was done, gram negative bacteria showed to be, in general, broadly predominant in marine habitats (Delille 1993), coastal zones (Tearle and Richard, 1987; Line, 1988) or in terrestrial habitats covered with vegetation (Heal et al., 1967). This correlate with the results presented here and could explain the fact that, in spite of the known capacity of the Gram positive bacteria to produce and secrete proteases, only a few of the selected strains were Gram positive. With respect to the generic composition, *Pseudomonas* was the most widely represented genus. This is in accordance with other studies where the microflora was analyzed, showing that *Pseudomonas* is the predominant genus in many Antarctic marine environments (Mac Cormack and Fraile, 1990), fresh waters and coastal soils (Meyer et al., 1967). This may be due to the considerable ability of *Pseudomonas* to adapt and multiply even with low nutrient supply.

The different strains showed variable activity levels in submerged cultures, which was not only due to their enzyme but also biomass production capacity. The latter, obviously determines in part the activity of the cell-free supernatants. Therefore, the aim of this work was not only to search for proteases but also to study their characteristics and the factors influencing the production. The strains which showed none or very low levels of proteolytic activity in culture supernatants were discarded.

The low temperature optimum for proteolytic activity found for many proteases (10-15°C lower than Subtilisin) is obviously a consequence of an adaptation to the conditions of the habitat. Psychrotrophic microorganisms are never confronted with high temperatures (over 40°C) in their environment, that is why their enzymes show an accordingly low thermostability and lower optimum temperature for activity than the corresponding mesophiles (Feller et al., 1996). Having high enzyme activities in the low temperature range (below 20°C) is a requirement for substrate hydrolysis, and thus for survival, and this constitute a way of adaptation of psychrotrophs and psychropiles (Schinner et al., 1992). In addition, the majority of the proteases with optimum temperature at 40°C had a neutral pH optimum, possibly influenced for the neutral pH of culture media used for isolation as well as the pH of the habitat explored.

By developing proteolytic activity of culture supernatants on gelatin-SDS-PAGE, it was possible to observe that some strains produced only one protease, being them selected for further studies if their optimum temperature was of interest, because they are easier to purify and characterize than a mixture of proteins. Nevertheless, the majority of the strains produced a multiple band profile, which might be the result of active fragments of self-digestion or the activity of more than one protease produced. The likely synthesis of more than one protease, which was observed mainly in strains of marine origin, could be thought as an estrategy to better face the fluctuating supply of nutrients as well as to enhance the uptake of proteins in oligotrophic environments.

Given that a biotechnological process based on the activity of an obligate psychrophile would be excessively expensive and complex, psychrotrophic

organisms, able to produce and secrete enzymes with high activity at low temperatures, are potentially useful to support an enzyme production process at moderate temperature (20-25°C). This process will yield an enzyme with important activity at temperatures significantly lower than that used at present.
To conclude, the results presented here suggest that the selected psychrotrophic strains are potentially useful for industrial applications, and that further studies will be necessary to optimize the natural capability of these strains to produce and secrete proteases. Moreover, we would like to emphasize the relevance of the Antarctic environment as a source of psychrotrophic microorganisms whose physiological characteristics are often unusual compared with the corresponding mesophiles (Shivaji et al., 1989) and which offer new possibilities in the field of the biotechnology.

References

Bahn M., Schmid R.D. (1987) Enzymes for detergents. Biotec 1: 119-130.

Delille D. (1993) Seasonal changes in the abundance and composition of marine heterotrophic bacterial communities in an Antarctic coastal area. Polar Biol., 13:463-470.

Feller G., Narinx E., Arpigny J.L., Aittaleb M., Baise E., Genicot S., Gerday Ch. (1996) Enzymes from psychrophilic organisms. FEMS Microbiology Reviews, 18: 189-202.

Heal O.W., Bailey A.D., Latter P.M. (1967) Bacteria, Fungi and Protozoa in Signy Island soils compared with those from a temperate moorland. Philosophical Transactions of the Royal Society (London), Series B252:191-197.

Heussen, Ch. and Dowdle, E.B. (1980) Electrophoretic analysis of plasminogen activators in polyacrilamide gels containing sodium dodecyl sulfate and copolymerized substrates. Anal.Biochem., 102, 196-202.

Keay L., Wildi B.S. (1970) Proteases of the genus *Bacillus*. I. Neutral proteases. Biotechnol Bioeng, 12:179-212.

Law B.A. (1979) Reviews of the progress of dairy Science: Enzymes of psychrotrophic bacteria and their effects on milk and milk products. J Dairy Res, 46:573-588.

Line M.A. (1988) Microbial flora of some soils of Mawson Base and the Vestfold Hills, Antarctica. Polar Biology, 8:421-427.

Lyman J., Fleming R.H. (1940) Composition of sea water. J Mar Res, 3:134-146.

Meyer G.H., Morrow M.B., Wyss O. (1967) Bacteria, fungi and other biota in the vicinity of Mirnyy Observatory. Antarctic J. U.S., 2:248-251.

Molin G., Stenstrom I., Ternstrom A .(1983) The microbial flora of herring fillets after storage in carbon dioxide, nitrogen or air at 2°C. J Appl Bacteriol, 55:49-56.

Morita R.Y. (1975) Psychrophilic bacteria. Bacteriol Rev, 39:144-167.

Schiner F., Margesin R. and Pumpel T. (1992) Extracellular protease-producing psychrotrophic bacteria from high Alpine habitats. Arctic and Alpine Research, 24: 1: 88-92.

Shewan J.M. (1971) The microbiology of fish and fishery products. A progress report. J Appl Bacteriol, 34:299-315.

Shewan J.M., Hobbs G., Hodkiss W. (1960a) A determinative scheme for the identification of certain genera of Gram-negative bacteria, with special reference to the *Pseudomonadaceae*. J Appl Bacteriol, 23:379-390.

Shewan J.M., Hobbs G., Hodkiss W. (1960b) The *Pseudomonas* and *Achromobacter* groups of bacteria in the spoilage of marine white fish. J Appl Bacteriol, 23:463-468.

Shivaji S., Shyamala Rao N., Saisree L., Sheth V., Reddy G.S.N., Bhargava P.H. (1989) Isolation and identification of *Pseudomonas* spp from Schirmacher Oasis, Antarctica. Appl. Environ. Microbiol., 55:767-770.

Tearle P.V., Richard K.J. (1987) Ecophysiological grouping of Antarctic environmental bacteria by API20 and fatty acid fingerprints. J Appl.Bacteriol, 63:497-503.

Some Biochemical Data on Fish and Southern Elephant Seals from Potter Cove

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Within the Antarctic marine ecosystem there are many species considered key organisms due to the importance of their ecological roles and because they are sensitive to and reflect changes in the environment. Several of these species, particularly the vertebrate predators, are already the subject of current research or monitoring international programmes such as CS-EASIZ, CCAMLR, SO-GLOBEC, among others.

In the Antarctic waters the Nothothenidae family, is of particular importance for the commercial fisheries (Tranter, 1982). Nototheniids (as *Notothenia coriiceps*, a demersal fish) are important components of the coastal marine communities and play a significant role in linking the benthic and pelagic systems.

Marine mammals are also important components of the Antarctic ecosystem, and can influence biological processes in a number of ways. Most populations of Southern elephant seals are highly dispersed for most of the year but concentrate on land for breeding and moulting (Ling and Bryden, 1981). At these times their populations can be assessed most easily. These seals are among the dominant top predators in Southern Ocean ecosystems and the fluctuations in their populations, patterns of growth, and life histories provide a potential source of information about environmental variability.

Several fish species as well as the Southern Elephant seal have been subject of detailed studies at Sub-Antarctic and Antarctic localities. Comparative studies on the biology of these species at Potter Cove, King George Island, South Shetland Islands, should provide valuable information on baseline data for fish communities and seal populations. Too little is known about these species at this area to make sensible recommendations for key organisms, key ecological processes and key biological communities for future research. Since a decade ago, relevant biochemical and physiological studies are being undertaken at Jubany Station, located at Potter Cove. These studies should provide important background data for the understanding of the influence of seasonal, inter-annual and long-term changes in the nutrient availability in this area on fish and mammals communities.

This work is part of the Research Programme undertaken by the Argentine Antarctic Institute and the University of Buenos Aires from 1989; the research projects were focused on two main subjects:

1) Fish (Main investigators: Márquez, M.E.I. and Casaux, R.J.):
Analysis of biochemical and nutritional characteristics of Antarctic fish, mainly nototheniids, and their main preys throughout the food web at Potter Cove area, related to the profit of species.

2) Mammals (Main investigators: Márquez, M.E.I. and Carlini, A.R.): Analysis of the variation in milk chemical composition, and immunological studies on

Southern elephant seal (*Mirounga leonina*), during lactation and moulting, along different field seasons at Stranger Point.

Results and discussion

1) Biochemical and nutritional characteristics of fish and their preys

1.1) Fish plasma proteins

A study of total plasma proteins in *Notothenia coriiceps* (previously known as *N. neglecta*) and *Notothenia rossii* was carried out as part of a systematic research (Márquez, 1994a). Determinations of sex, size, and estimations of the health state based on the presence of parasites in the liver, and of the nourishing state based on the stomach content were done in the specimens under study; also Gonadal and Hepatosomatic indexes as well as the Mean Condition Factor (K) were calculated. Plasma protein fractions were determined by electrophoresis on cellulose acetate, aimed at determining and quantifying its different compounds (Márquez, 1994b). The relative mobilities were compared against reference plasma. A quantitative evaluation was carried out dosing the proteinograms by densitometry and by elution.

From the analysis of the data obtained it may be concluded that: a) fish plasma showed a total protein concentration lower than in mammals; b) in both species and sexes it was observed that the total plasma protein value in the parasitized specimens was significantly lower than that observed in unparasitized specimens; these levels can be used as indicators of internal parasitism or disease; c) intraspecific and interspecific variations, as well as qualitative and quantitative similarities were found in the fish electrophoretic profiles. The results allowed to consider the application of the methodology used in typifying the species based on a biochemical criterion.

1.2) Chemical composition of fish tissues and seasonal variations

Juvenil and adult specimens from both sexes of *Notothenia coriiceps*, *Notothenia rossii* and *Gobionotothen gibberifrons* (commonly known as Antarctic cods), were caught during an annual cycle from March 1988 to March 1989. The following parameters were determined: a) the filleting percentage yield; b) proximal composition of fillets (skinned and without pin bones): water content, lipids, protein, ash and carbohydrates; c) liver and gonad fat contents; d) fillet caloric content; e) nitrogen fractions (total, non-protein and protein nitrogen) and total volatile basic nitrogen. Data were grouped in three periods: summer, autumn and spring, with regard to the reproductive cycle of the species (Casaux et al., in press; Márquez et al., 1994; 1995; 1996a, b; Mazzotta et al., 1993).

The average caloric content for the three species considered fluctuated between 65.73 and 91.30 Cal/100 g of flesh, wet weight. Lipids provided between 6.91 and 18.42% of the flesh total caloric content, whereas protein did between 73.34 and 91.85%. Due to the low flesh fat content (0.53 - 1.84%, w.w.), these species were classified as lean, being the liver the main reservoir of body fat. The high flesh protein levels (14.52 - 19.88%, w.w.) corresponded to a high protein nitrogen level, which represented between 79.09 and 87.84% from total nitrogen.

Notothenia coriiceps showed that chemical components fluctuated yearly, depending on periods related to the reproductive cycle (total minerals = ash); reproductive periods and maturity stage (lipids); maturity stage and to the interaction between reproductive periods and sex (protein) of specimens. Significant variations on the chemical components in *N. rossii* were found during the year, according to the biological cycles of the species. The fluctuations observed in some biochemical fractions in *G. gibberifrons* were no significant, due to the high variability in the data and the sample size.

These antarctic fish species showed to be a high protein and low fat food resources, potentially suitable for human and animal consumption.

1.3) Tissue Micronutrient levels and fluoride contents in fish and preys

Little information exists on metal accumulation in fish and other marine organisms destined for direct or indirect human consumption, in species from the Southern Ocean such as *Notothenia coriiceps*. Thus, the aim of this study was to determine the levels of Zn, Cu, Mn and Fe in different fish tissues, in view of their importance as essential micronutrients, the potential commercial exploitation of *N. coriiceps*, and the posibility of the use of this species as indicator of changes in the Antarctic environment (Márquez et al., 1997).

The fish size and mass (mean ± sd) were: 34.3 ± 1.2 cm and 650.2 ± 94.3 g for females, and 36.0 ± 2.8 cm and 706.5 ± 116.0 g for males. The values for all the elements analysed in both sexes were significantly the lowest in muscle tissue; whereas, in general, the values in liver and gonad of males and females, respectively, were significantly the highest (Casaux et al., 1997). Despite of the scarce differences in the size and mass of the specimens, the Cu levels in liver, muscle and kidney were significantly inversely correlated to females mass as well as in gonad levels to males length. Fe largely presented the highest concentrations whereas Cu and Mn the lowest ones.

The concentration of minerals (Márquez et al., 1997) was higher by several orders of magnitude in biological tissues than in seawater (Caroli et al., 1996). Furthermore, the amounts found in the organisms were a good indication of the bioavailability of these substances in the environment.

It is important to mention the existence of high Zn and Cu concentrations in the sediments of Potter Cove (Scagliola et al., 1995), as well as Mn levels reported in another area (Caroli et al., 1996); sediments would be accidentally eaten during the prey catching (Casaux et al., 1990).

According to the available data and considering the prey importance in the diet of *N. coriiceps*: krill> gammarids amphipods> algae (Casaux et al., 1990), their mineral concentrations (Márquez, 1991; Moreno et al., 1989) suggested their importance as a source of these micronutrients. Considering that algae are usually underestimated by the diet quantitative methods, their importance as a source of minerals could be higher than expected.

Fe, Zn, Mn and Cu muscle concentrations were lower in *N. coriiceps* than in fish preys, this fact suggest that these minerals were not accumulated in the flesh of this fish. The Zn, Fe and Mn contents in some prey species were lower than these mineral levels in liver of *N. coriiceps*. On the contrary, some of the Cu values observed in prey species were comparable to or higher than those of the predator.

Variability among species showed that mineral mean values on the edible portion of the Antarctic cod agreed with the reported ones for hake, cod, herring and mackerel (González Badano, 1988; Anon., 1989), however, the Fe levels were slightly higher than those from the literature.

As the Antarctic Ocean is far from the major source of industrial pollution, concentrations of minerals accumulated in Antarctic animals may be regarded as fairly close to the natural baseline level.

The search for new sources of marine animal protein for human consumption, animal feed and industrial purposes, increased interest in the possible utilization of Antarctic crustacean and fish resources. The aim of this work was to analyze the variations of fluoride levels in tissues of different Antarctic species: krill (*Euphausia superba*), gammarid amphipods, *N. coriiceps*, *N. rossii, G. gibberifrons* and *Chaenocephalus aceratus* (Márquez et al., 1992). The largest amount of fluoride 986.3 - 1619.0 ppm dry wt., was found in the whole krill, whereas peeled meat showed 45.6 ppm dry wt. In whole amphipods, very high fluoride levels were found: 1182.0 ppm dry wt. This indicated that fluoride was largely accumulated in exoskeleton. Fish showed a considerable accumulation of fluoride in their skeletal structures (fish residues after filleting) 27.4 - 250.8 ppm dry wt. Although these fish species mainly feed on krill and amphipods, the muscle tissues (skinned and filleted) showed only a low level of fluoride: <1 - 22.0 ppm dry wt. The obtained results allowed to assume that only the muscle tissue of Antarctic crustacean and fish species may comply with requirements for human consumption.

2) STUDIES ON MILK AND SERUM OF PINNIPEDS

The research is focused on interaction among the immunological and nutritional status with pup growth studies.

2.1) Chemical composition of milk

An analysis of milk constituents during various stages of lactation in the southern elephant seal was carried out (Carlini et al., 1994). Total nitrogen (TN), non-protein nitrogen (NPN), sugar, fat, ash and water were measured, and true protein and energy content were calculated. The results showed a high degree of variation in water and fat concentrations among samples at different stages of lactation. During the first 20 days the fat content of milk increased from about 12 to approximately 52%, while water content fell from 70 to 33%. The composition of milk changes rapidly during the first days post-partum. Protein, minerals and sugar appear to remain stable after the fourth day of lactation. Milk samples contain significant levels of sugars; thin layer chromatography indicates the presence of lactose and glucose together with other unidentified components. There is evidence of a striking change in composition of the milk in the later part of lactation, the progressive increase in the fat:water ratio is abruptly reversed just prior to weaning.

Milk protein fractions were subjected to polyacrylamide gel electrophoresis (Ronayne de Ferrer et al., 1996). Samples from different days of lactation gave similar qualitative electrophoretic patterns. Caseins and whey proteins each consisted of several protein entities (4 and 5 distinct bands respectively). Casein constituted only about 30% of the protein nitrogen, the remaining 70% being derived from whey proteins. There was some variation in concentration of casein and whey proteins as a function of time.

2.2) Milk Immunoglobulins

Immunoglobulin A (IgA) levels in milk samples were determined throughout the suckling period (approximately 23 days) (Márquez et al., 1995). The IgA concentration in southern elephant seal milk was lower than in other mammals and, unlike most mammalian milk, was not higher during early lactation. There was not a definite pattern in IgA levels, which fluctuated within narrow limits (mean ± SD, 30.81 ± 6.38 mg IgA/100 g milk). This finding becomes the first evidence in Southern elephant seal of the possibility of transmission of passive immunity after birth involving secretion of IgA in the milk.

2.3) Serum Immunoglobulins

An animal's health and physiological state can also be reflected in measurements of blood parameters.

Immunoglobulin A (IgA) and M (IgM) concentrations in serum samples from female - pup pairs of southern elephant seal during the suckling period were performed by radial immunodiffusion technique on agarose plates (Márquez et al., in press a; b).

Female IgA serum levels (mean ± SD, 19,0 ± 6.4 mg/dL) were higher than pup levels (9.2 ± 3.6). Both groups did not show a definite trend throughout the suckling period, with no significant differences in relation to stages of lactation. The origin of pup IgA serum level on the first day of life is not known; it may originate from endogenous synthesis at the time of birth, or, this may be due to the transfer via milk to offspring of passive humoral immunity. Prior to weaning, IgA level in these pups reaches approximately 50% of that occurring in adult females.

Female IgM levels (range 123.5 - 613.0 mg/dL) were significantly higher than pup levels (5.9 - 123.6 mg/dL). Both groups showed an increasing trend throughout the entire suckling period, with significant differences in relation to stages of lactation. Pup IgM levels on the first day of life (mean ± SD, 7.6 ± 2.9 mg/dL) suggest that the *in utero* endogenous synthesis takes place before birth.

References

Anon. (1989): *Food Composition and Nutrition Tables 1989/90* .4th. edition. Wissenschaftliche Verlagsgesellschaft mbH Stuttgart.

Carlini, A.R.; Márquez, M.E.I.; Soave, G.; Vergani, D.F. and Ronayne de Ferrer, P.A. (1994): Southern elephant seal, *Mirounga leonina*: composition of milk during lactation. *Polar Biology, 14*, 37-42.

Caroli, S.; Senofonte, O.; Caimi, S.; Pauwels, J. and Kramer, G.N (1996): Planning and certification of new multielemental reference materials for research in Antarctica. *Mikrochimica Acta, 123*, 119-128.

Casaux, R.J.; Mazzotta, A.S. and Barrera-Oro, E.R. (1990): Seasonal aspects of the biology and diet of nearshore nototheniid fish at Potter Cove, South Shetland Islands, Antarctica. *Polar Biology, 11*, 63-72.

Casaux, R.J.; Mazzotta, A.S. and Márquez, M.E.I. (in press):Seasonal changes in protein and total mineral contents of muscle tissue in *Notothenia coriiceps*.

Casaux, R.J.; Vodopivez, C.; Márquez, M.E.I. and Curtosi, A. (1997): Levels of essential micronutrients (Zn, Cu, Mn and Fe) in different tissues of the Antarctic fish *Notothenia corriceps*. *Abstract of Experimental Biology '97 (FASEB '97: Federation of American Societies for Experimental Biology)*, New Orleans, LA, U.S.A., April 1997. Published in *The FASEB Journal, 11(3)*, p. A417.

González Badano, R. (1988): Estudio comparativo de la composición química, contenido aminoacídico y valor nutritivo de la merluza fresca, y congelada, y salada, secada y rehidratada. *Archivos Latinoamericanos de Nutrición, 37(2)*, 330-344.

Ling, J.K. and Bryden, M.M. (1981): Southern Elephant Seal *Mirounga leonina* Linnaeus, 1758. *Handbook of Marine Mammals, 2, Seals*, 297-327. Ridway, S.H. and Harrison, R.J. (eds.). London: Academic Press.

Márquez, M.E.I. (1991): Contenido de vitaminas y minerales en el krill antártico. *La Industria Cárnica Latinoamericana, 86*, 26-33.

Márquez, M.E.I. (1994a): Estudio preliminar de la concentración de las proteínas plasmáticas en *Notothenia neglecta* y *Notothenia rossii*. *Contribución del Instituto Antártico Argentino, Nº 415*. Buenos Aires, Argentina.

Márquez, M.E.I. (1994b): Proteínas plasmáticas de las especies antárticas *Notothenia neglecta* y *Notothenia rossii*: análisis electroforético. *Contribución del Instituto Antártico Argentino, Nº 421*. Buenos Aires, Argentina.

Márquez, M.E.I.; Carlini, A.R.; Slobodianik, N.H.; Ronayne de Ferrer, P.A. and Godoy, M.F. (in press, a): IgA serum concentration in females and pups of Southern elephant seal during the lactation period at Stranger Point, Antarctica. *Proceedings Cuartas Jornadas sobre Investigaciones Antárticas*, Buenos Aires, Argentina.

Márquez, M.E.I.; Carlini, A.R.; Slobodianik, N.H.; Ronayne de Ferrer, P.A. and Godoy, M.F. (in press, b): Immunoglobulin M serum levels in females and pups of Southern elephant seal (*Mirounga leonina*) during the suckling period. *Comparative Biochemistry and Physiology.*

Márquez, M.E.I.; Casaux, R.J. and Mazzotta, A.S. (1994): Variación estacional de la composición del tejido muscular del "bacalao antártico" (*Notothenia neglecta*). *Proceedings VI Congreso Argentino de Ciencia y Tecnología de Alimentos y 1er. Encuentro de los Técnicos de Alimentos del Cono Sur*, pp. 383-385. Buenos Aires, Argentina. April 1994.

Márquez, M.E.I.; Casaux, R.J. and Mazzotta, A.S. (1995): Análisis de la composición química del tejido muscular de *Gobionotothen gibberifrons* a lo largo de un ciclo anual. *La Industria Cárnica Latinoamericana, 101*, 33-37.

Márquez, M.E.I.; Casaux, R.J. and Mazzotta, A.S. (1996a): Bacalaos antárticos: peces magros de alto contenido proteico. *La Industria Cárnica Latinoamericana, 105*, 34-39.

Márquez, M.E.I.; Casaux, R.J. and Mazzotta, A.S. (1996b): Cambios estacionales en la composición química del tejido muscular de *Notothenia rossii*. *La Industria Cárnica Latinoamericana, 102*, 22-28.

Márquez, M.E.I.; Mazzotta, A.S. and Casaux, R.J. (1992): Niveles de fluor en krill, anfípodos y peces antárticos en relación al aprovechamiento de las especies. *La Industria Cárnica Latinoamericana, 88*, 32-35.

Márquez, M.E.I.; Slobodianik, N.H.; Ronayne de Ferrer, P.A.; Carlini, A.R.; Vergani, D.F. and Daneri, G.A. (1995): Immunoglobulin A levels in Southern elephant seal (*Mirounga leonina*) milk during the suckling period. *Comparative Biochemistry and Physiology, 112B (3)*, 569-572.

Márquez, M.E.I.; Vodopivez, C.; Casaux, R.J. and Curtosi, A.(1997): Essential micronutrient levels in muscle and liver of *Notothenia corriceps* related to the contents in its preys. *Proceedings VII COLACMAR (Congreso Latinoamericano sobre Ciencias del Mar), 2*, , 138-139. Santos, San Pablo, Brasil.

Mazzotta, A.S.; Casaux, R.J. and Márquez, M.E.I. (1993): Seasonal changes in lipid content of some tissues in *Notothenia neglecta*. *Oebalia, 19*, 105-114.

Moreno, J. de; Pérez, A.; Moreno, V.; Vodopivez, E. and Leva, D. (1989): Monitoreo de metales pesados en la biota marina antártica. *Abstract of the Jornadas Nacionales de Ciencias del Mar*, Puerto Madryn, Chubut, Argentina, September 1989.

Ronayne de Ferrer, P.A.; Gonzalez Colaso, R.A.; Márquez, M.E.I.; Carlini, A.R.; Vergani, D.F. and Daneri, G. (1996): Southern elephant seal, *Mirounga leonina*. II: studies of milk protein fractions by gel-electrophoresis. *Polar Biology, 16*, 241-244.

Scagliola, M.; Pobtet, A.; Vodopivez, C.; Curtosi, A. and Marcovecchio, J. (1995): Distribución de metales pesados en sedimentos marinos superficiales de la Caleta Potter, Isla 25 de

Mayo (Shetland del Sur), Antártida. *Proceedings Terceras Jornadas de Comunicaciones sobre Investigaciones Antárticas*, pp. 401-408. Buenos Aires, Argentina, October 1994.

Tranter, D.J. (1982): Interlinking of physical and biological processes in the Antarctic Ocean. *Oceanogr. Mar. Biol. Ann. Rev., 20,* 11-35.

Particle retention and pumping rates of seven species of Antarctic suspension feeding animals

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Suspension feeding animals play an important role in bentho-pelagic coupling throughout the oceans (Flint & Kamykowski 1987; Doering et al. 1986; Ahn 1993). The uptake of phytoplancton and particulate organic matter from the water column followed by the biodeposition of faeces and pseudofaeces is known to be one of the major trophic pathways in marine ecosystems.

Also Antarctic soft bottoms reveal a rich and diverse fauna of suspension feeders, often dominated by sponges and ascidians (see Starmans 1997, Kowalke 1998), which thus form a major part in pelagic-benthic interactions. Despite their dominance, their ecological importance is still poorly investigated in Antarctic waters.

Potter Cove houses a variety of suspensivores of up to 25 ind/m^2 which are mainly ascidians, the clam *Laternula elliptica* and the sponge *Mycale acerata* (Sahade et al. 1998, Kowalke 1998).

As pumping and filtration rates are essential to calculate the energy budget of these important trophic groups in an ecosytem, the dominant ascidians *Ascidia challengeri*, *Cnemidocarpa verrucosa*, *Corella eumyota* and *Molgula pedunculata*, the sponges *Mycale acerata* and *Isodictya kerguelensis* and the clam*Laternula elliptica* were choosen to be investigated.

Material and Methods

The animals were collected by divers between december 1995 and february 1996 and immediately put into aerated flow-through aquaria between 8l and 25l water capacity according to size of the animals. They were kept for at least one week for acclimatisation before starting the experiments. The aquaria were artificially cooled to maintain a temperature of 1°C.

The water stream was cut off for 40 hours, the aeration providing sufficient turbulence for stirring. Every 8 hours 20 ml water were siphoned off and immediately analysed on a Elzone Particle Counter 280. The animals were continously pumping as could be concluded from permanently open siphons.

Two aquaria without animals were used as blanks for the calculation of cell sedimentation and fission rates. The calculation of pumping rates (PR) was done using the formula of Williams (1982), the relationship between rate and weight was calculated with the allometric equation: $PR = aW^{b}$, where b is the slope of the regression line in a double log-plot, W he weight and a the pumping rate of a 1g standard animal.

Dry weight and ash free dry weight were determined using 60°C for two days and 500°C for 5 hours respectively.

Results

Retention efficiency

No species retained the particles with an efficiency of 100% (fig.1). *C. verrucosa* reached the highest measured value with an efficiency of 90% for particles > 5 µm. Two distinct ascidian groups can be distinguished, the first *A. challengeri* and *C. verrucosa*, which start filtration from 1,3 µm on and reach a maximum efficiency at a smaller particle size as the second group, *C. eumyota* and *M. pedunculata*, which filter from 1 µm on.

The sponges filter down to a particle size of 0,3 µm, thus exploiting the bacterial size range. A gap, where no filtration takes place, lies around 1 µm.

The bivalve *L. elliptica* covers a range similar to the ascidians, but having its major abundances in different depths in Potter Cove, competition is unlikely to occur.

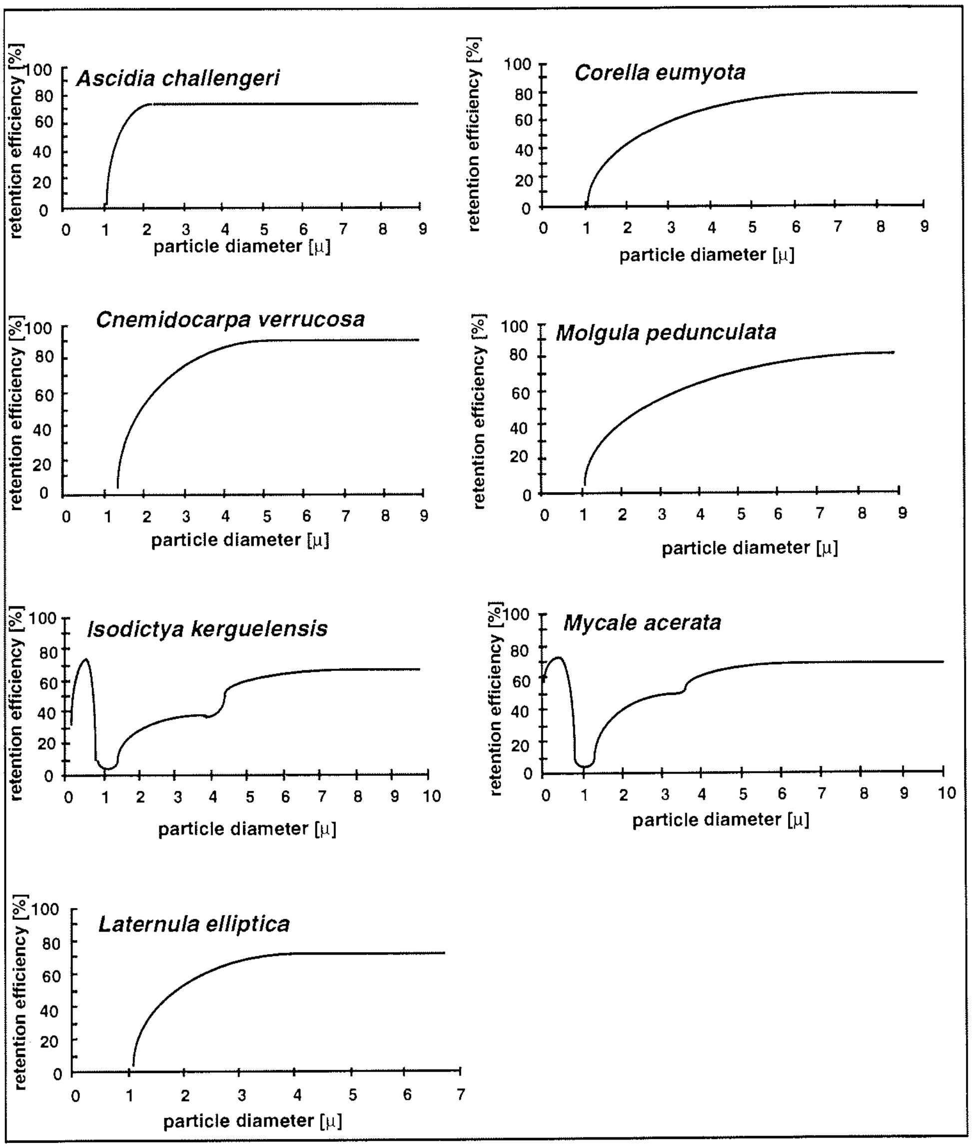

fig. 1: retention efficiencies of seven species of benthic Antarctic suspension feeders

Pumping rates

In general the ascidians tend to have higher pumping rates than the sponges or the clam (tab.1). The regression coefficients which should theoretically be around

0,75 (Wieser 1986), are always much lower, besides the ash-free dry weight coefficient for *A. challengeri.* This could indicate a surpressed metabolism due to excretion or CO_2 enrichment during the experimental period, what can regularly be found in ascidians (Holmes 1973).

tab. 1: Pumping rates, regression coefficients for ash free dry weight (AFDW) and dry weight (DW) and no. of animals measured

Art	PR/g AFDW • h	b	PR/g DW • h	b	n
A. challengeri	304 ml	0,80	191 ml	0,43	21
C. verrucosa	347 ml	0,39	260 ml	0,28	22
C. eumyota	250 ml	0,44	148 ml	0,34	8
M. pedunculata	349 ml	0,38	200 ml	0,41	22
M. acerata	180 ml	0,44	75 ml	0,43	7
I. kerguelensis	220 ml	0,31	139 ml	0,31	16
L.elliptica	176 ml	0,46	127 ml	0,41	21

Discussion

Potter Cove is a small inlet dominated by a strong winds and an enourmous run off of glaciar meltwater which carries terrigenous sediment into the water (see Varela, this volume). Organisms living under these conditions have to cope with these, mainly anorganic, particles in the size range between 0,9 and 6 µm as they sink to the bottom and are regularly resuspended. Especially suspension feeding animals are threatened to clogg their filtering devices and thus have to be adapted to guarantee their metabolic needs.

The fact, that no species retained any particle size with an 100% efficiency could be related to this sediment problem. Avoiding a complete retention of all particles lowers the probability to clog the filtering structures and a certain unefficiency thus enhances the survival.

Retention efficiencies play a major role in separating niches and reducing competition (Stuart & Klumpp 1984), as indicated by the Potter Cove suspension feeders as well. *A. challengeri* and *C. eumyota* occur together, like *C. verrucosa* and *M. pedunculata* do. The coocurring species differ in their demands. The bivalve, *Laternula elliptica,* which has a similar efficiency like the sea squirts, has its major distribution in lower depths than the ascidians despite sufficient space in greater depths (Sahade et al. 1998). The sponges are able to filter into the bacterial range. The depression around 1µm particle diameter stems from two different filtering mechanisms employed by these animals. Bigger sized particles are taken up in the inhalant channels whereas particles in the size of small bacteria are caught by the fine flagella of the choanocyte chamber cells. Particles in the size of about 1 µm are to small to get phagozytized in the inhalant channels and to big for the choanocytes.

The pumping rates of all species lie far below those of temperate species (for a compilation see Kowalke 1998). This could be influenced by the closed-vessel system experimental procedure, which can lead to surpression of pumping rates of sponges (Vogel 1974, 1977) and ascidians (Holmes 1973). Nevertheless the striking difference observed here cannot be explained by the set up alone. Two main factors control pumping rates in the cold, the reduced overall metabolism and the physical properties of the seawater. Metabolic reactions, compared to tropical species, should be lowered by a factor up to 9 according to van´t Hoff´s law. Even if this simple relationship cannot easily be used to compare morphological similar species living under different historical and ambient conditions, it holds true as a trend (Thiel et al. 1996).
Water of low temperature has a significant higher viscosity than temperate water, which affects the resistance to water flow in the water pumping systems of the animals. Hoegh-Guldberg (1991), using data on asteroid larvae and Jørgensen (1990), working with the blue mussel *Mytilus edulis,* hypothesized that viscosity of seawater is the only important factor controlling pumping rates as a strong correlation between rates and the kinematic viscosity could be observed, not leaving much room for other factors like ciliary beat frequencies. Astonishingly high correlation values yielded a comparison of pump rates of Antarctic ascidians and sponges with animals from warmer waters, despite different life histories and en-

vironments (see Kowalke 1998). This might be annother indicator of seawater viscosity as the most important factor controlling these rates.

Literature:

Ahn, I. 1993. Enhanced particle flux through the biodeposition by the Antarctic suspension feeding bivalve *Laternula elliptica* in Marion Cove, King George Island. J. Exp. Mar. Biol. Ecol. **171**, pp 75-90

Doering, P.H. and Oviatt, C.A. 1986. Application of filtration rate models to field populations of bivalves: an assessment using experimental mesocosms. Mar. Ecol. Prog. Ser. **31**, pp 265-275

Flint, R.W. and Kamykowski, D. 1987. Benthic nutrient regeneration in South Texas coastal waters. Estuar. Coast. Shelf Sci. 18, pp 221-230

Hargrave, B.T. 1973. Coupling carbon flow through some pelagic and benthic communities. J. Fish. Res. Board Can. **30**, pp. 1317-1326

Hoegh-Guldberg, O., Welborn, J.R. and Manahan, D.T. 1991. Metabolic requirements of Antarctic and temperate asteroid larvae. Ant. J. US **26 (5)**, pp 170-172

Holmes, N. 1973. Water transport in the ascidians *Styela clavata* (Herdman) and *Ascidiella aspersa* (Müller). J. Exp. Mar. Biol. Ecol. **11**, pp 1-13

Jørgensen, C.B. 1990. Bivalve Filter Feeding: Hydrodynamics, bioenergetics, physiology and ecology. Olsen & Olsen, Fredensborg, 140 pp

Kowalke, J. 1998. Energieumsätze benthischer Filtrierer der Potter Cove (King George Island, Antarktis). Rep. Pol. Res. **286** 147 pp

Sahade, R., Tatián, M., Kowalke, J., Kühne, S. and Esnal, G. 1998. Benthic faunal associations on soft substrates at Potter Cove, King George Island, Antarctica. Pol. Biol. **19**. pp 85-91

Starmans, A. 1997. Vergleichende Untersuchungen zur Ökologie und Biodiversität des Megaepibenthos der Arktis und Antarktis. Diss. Uni Bremen, 140 pp

Stuart, V. and Klumpp, D.W. 1984. Evidence for food-resource partitioning by kelp-bed filter feeders. Mar. Ecol. Prog. Ser. **16**, pp 27-37

Thiel, H., Pörtner, H.O. and Arntz, W.E. 1996. Marine Life at low temperatures - a comparison of polar and deep-sea characteristics. in: Uiblein, F., Ott, J.,Stachowitsch, M. (eds). Deep-sea and extreme shallow water habitats: affinities and adaptations. Biosystematics and Ecology Series **11**, pp 183-219

Vogel, S. 1974. Current-induced flow through the sponge *Halichondria*. Biol. Bull. Mar. Biol. Lab. Woods Hole **147**, pp 443-456

Vogel, S. 1977. Current-induced flow through living sponges in nature. Proc. Nat. Acad. Sci. **74**, pp 2069-2071

Wieser, W. 1986. Bioenergetik. Thieme Verlag Stuttgart, 245 pp

Williams, L.G. 1982. Mathematical Analysis of the Effects of Particle Retention Efficiency on Determination of Filtration Rate. Mar. Biol. **66**, pp 171-177

Zaret, R.E. 1980. Evolution and Ecology of Zooplancton Communities. University Press of New England, Hanover, New Hampshire. pp 3-9

Seasonality in reproduction of Antarctic Ascidians (*Molgula pedunculata*, *Cnemidocarpa verrucosa* and *Pyura setosa*)

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INTRODUCTION

Ascidians are important members of several benthic Antarctic communities (Jazdzewski et al. 1986, Kirkwood & Burton 1988, Mühlenhardt-Siegel 1988, Galéron et al. 1992, Gerdes et al. 1992, Sáiz-Salinas et al. 1997), moreover in Potter Cove where they are the dominant faunal group (Sahade et al. 1998a, 1998b).

Sessile marine organisms are permanently attached to substrates and reproduce successfully only, if their larvae are able to locate available space on a suitable substrate. The colonization success of certain invertebrates is well correlated to the density of their larvae available for settlement (McGuiness & Davies 1989, Hurlbut 1992). Thus, relative differences in the timing and reproductive output of sessile invertebrates may influence long term species survival and could help us to understand the processes underlying the patterns of the observed distribution.

The hermaphroditic nature of ascidians together with lecithotrophic nature of their larvae adds interest to reproduction studies, since autogamy becomes possible and energetic implications of reproductive output requires more relevance.

In tropical and temperate waters ascidian reproduction is mainly regulated by temperature, from continuous reproductive periods in warm waters to one or two annual peaks in temperate seas (Goodbody 1961, Millar 1971, 1974, Yamaguchi 1975, Becerro & Turon 1991, Durante & Sebens 1994). It has been suggested that the Antarctic invertebrates reproductive peaks, due to temperature stability in Antarctic waters, must be regulated by annual pulses of primary production and energy availability (Clarke 1987, 1988).

STUDY AREA AND METHODS

This study was carried out in Potter Cove (62º 14' S-58º 38'W), King George Island, South Shetland Islands, where the Argentinian station Jubany and the German Argentinian Dallmann Laboratory is situated. Five specimen of each species were collected by monthly SCUBA diving between December 1995 and May 1997. The organisms were dissected and the gonads fixed and conserved in 4% formalin. This tissue was then embedded in paraffin, dissectioned and stained with hematoxylin-eosine. A whole section of each gonad was examined by light microscopy and the diameter of each oocyte which appeared dissected at the nucleolus level was measured to a total of one hundred oocytes in each gonad. The oocytes were placed into 50 µm size classes, being class 5 the most mature stage and class 1 the unmature. The degree of maturity of testes was also noted and classified in four categories of male follicle development. We examined temporal patterns of reproduction in two ways, first we used a X^2 contingency table analysis to determine whether reproduction was independent of the season, secondly we applied analysis of variance (ANOVA) to identify significant peaks of reproduction.

RESULTS

The three ascidians species are hermaphroditic and the female portion occupied the central part of the gonads, while the male follicles appeared in the periphery. Both portions were present year round in the three species.

The course of vitellogenesis was continuous throughout the year, although oocytes of different stages were present during all the cycle, they mature gradually until the gonads appeared packed with fully vitellogenic oocytes, after the spawnig the gonad appeared empty with few immature oocytes. The development of male follicles is also gradually and the mature sperm occurs simultaneously with the mature oocytes.

The studied species exhibited strong seasonality in reproduction (table 1).

table 1: Seasonality of sexual reproduction. Data are the % of individuals sampled in each season, mature (+) and unmature (-), P values from contingency analyses.

	Mp		Cv		Ps	
	+	-	+	-	+	-
Summer 96	0	100	8	92	63	37
Fall 96	52	48	53	47	20	80
Winter 96	80	20	60	40	0	100
Spring 96	0	100	0	100	20	80
Summer 97	0	100	33	67	67	33
	P < 0,001		P < 0,001		P < 0,001	

Fecundity measured as number of mature oocytes/size showed significant differences in the annual cycle in the three species (*M. pedunculata* ANOVA; F = 6,735; P < 0,0001; *C. verrucosa*, ANOVA, F = 6,735; P < 0,0001; *P. setosa*, ANOVA, F = 5,504; P < 0,0001). *M. pedunculata* and *C. verrucosa* had their reproductive peaks at the end of the autumm, while *P. setosa* showed its reproductive peak during the Antarctic summer (figs. 1 and 2). In the case of *P. setosa* we had the oportunity to examine two reproductive periods, the 95-96 and 96-97 summer seasons, and we found a higher fecundity in the 96-97 than during the 95-96 period.

DISCUSSION

Monthly variations in gonad histology, fecundity and oocyte diameters indicate that the three species have reproductive cycles that consists of a single spawning season per year. Sperm and oocyte maturation takes place synchronously, indicating that these species are simultaneous hermaphrodites. This condition is found in other solitary ascidians, while other species show a protandrous condition (Svane & Lundalv 1981, 1982; Becerro & Turon 1991).

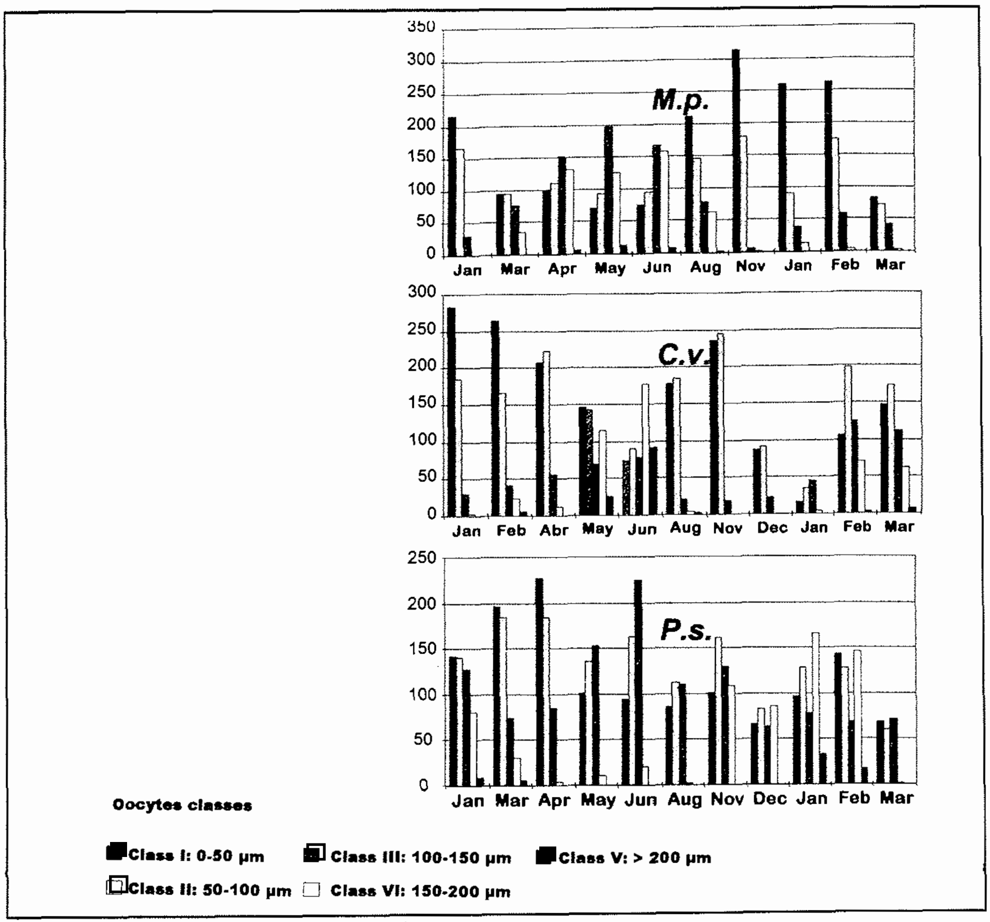

fig. 1: total oocyte number of each maturity stage.

The reproduction seasonality is differs in the three species, while *M. pedunculata* and *C. verrucosa* have their repoductive peaks from May to July (Antarctic winter) *P. setosa* reproduces between January and March (Antarctic summer). The case of *P. setosa* does not seem unusual, since a high correlation between reproductive periods and energy availability is expected. Moreover, this tendency was confirmed by the differences observed in the two spawning periods of *P. setosa*. The 97-97 season showed a higher fecundity than the 95-96 period, which was coincident with higher levels of primary productivity in this area during the the first season (Schloss 1997).

The case of *M. pedunculata* and *C. verrucosa* s different and seem paradoxical, these species reproduce during the austral winter, when the energy availability and food supply is very low compared with the summer season.

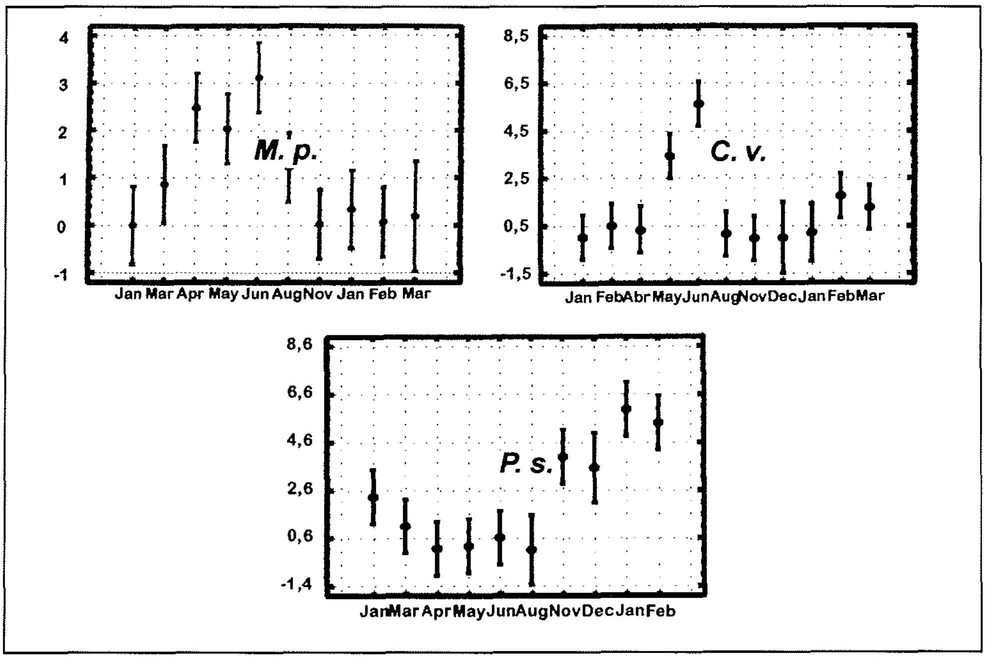

fig. 2: Temporal patterns of fecundity, expressed as the relationship of mature oocytes /size of an ascidian.

The reproduction during this period may imply a disadvantage for these species. However, these are the two most succcesful ascidian species in this ecosystem. This supports the idea of a reproduction strategy that avoids competition and mainly predation, which is probably more intense during summer. The energetic implications of this strategy are yet to be investigated.

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BIBLIOGRAPHY

Clarke, A.; 1987. Temperature, latitude and reproductive effort. Mar. Ecol. Prog. Ser. 38:89-99.

Clarke, A.; 1988. Seasonality in the Antarctic marine environment. Comp. Biochem. Physiol. 90B:461-473.

Durante, K. M.; Sebens K. P.; 1994. Reproductive ecology of the ascidians *Molgula citrina* Alder & Hancock, 1848 and *Aplidium glabrum* (Verrill, 1871) from the gulf of Maine, U.S.A. Ophelia 39:1-21.

Galéron, J.; Herman, R. L.; Arnaud, P. M.; Arntz, W. E.; Hain. S.; Klages, M.; 1992. Macrofaunal communities on the continental shelf and slope of the southeasthern Weddell Sea, Antarctica. Polar Biol. 12: 283-290.

Gerdes, D.; Klages, M.; Arntz, W. E.; Herman, R. L.; Galéron, J.; Hain, S. 1992. Quantitative investigations on macrobenthos communities of the southeastern Weddell Sea shelf based on multibox corer samples. Polar Biol. 12: 291-301.

Goodbody, I. 1961. Continuos breeding in three species of tropical ascidian. Proc. Zool. Soc. Lond. 136:403-409.

Hurlbut, C. J. 1992. Larval release and supply predict temporal variation in settlement of a colonial ascidian. Mar. Ecol. Prog. Ser. 80:215-219.

Jazdzewski, K.; Jurasz, W.; Kittel, W.; Presler, E.; Sicinski, J. 1986. Abundance and biomass estimates of the benthic fauna in Admiralty Bay, King George Island, South Shetland Islands. Polar Biol. 6: 5-16.

Kirkwood, J. M.; Burton, H. R. 1988. Macrobenthic species assemblages in Ellis Fjord, Vestfold Hills, Antarctica. Mar. Biol. 97: 445-457.

McGuiness, K. A.; Davies A. R. 1989. Analysis and interpretation of the recruit-settler relationship. J. Exp. Mar. Biol. Ecol. 134:197-202.

Millar, R.H.; 1971. The biology of Ascidians. Adv. Mar. Biol. 9:1-100.

Millar, R.H.; 1974. A note on the breeding season of three ascidians on Coral Reefs at Galeta in the Caribean Sea. Mar. Biol. 23:127-129.

Sahade, R.; Tatian, M.; Kowalke, J.; Kühne S. and Esnal, G.; 1998a. Benthic Faunal Associations in Soft Substrates at Potter Cove, King George Island, Antarctica. Polar Biol. 19: 85-91.

Sahade, R.; Tatian, M.; Kowalke, J.; Kühne S. and Esnal, G.; 1998b. Epifaunal Communities at Potter Cove, King George Island, Antarctica. Berichte zur Polarforschung - Reports on Polar Research. In press.

Sáiz-Salinas, J.I.; Ramos, A.; García, F. J.; Troncoso, J. S.; San Martín, G.; Sanz, C.; Palacin, C. 1997. Quantitative analysis of macrobenthic soft-bottom assemblages in South Shetland waters (Antarctica). Polar biol. 17: 393-400.

Schloss, I.; 1997. Escalas temporo-espaciales de variabilidad del fitoplancton costero Antártico. Ph. D. Tesis. F. C. E. N. U. B. A. 209pp.

Svane, I.; Lundalv, T.; 1981. Reproductive patterns and population dynamics of the perennial ascidian *Ascidia mentula* O.F. Muller, on the Swedish West Coast J. Exp. Mar. Biol. Ecol. 50:163-182.

Svane, I.; Lundalv, T.; 1982. Persistence stability in ascidian populations: long term population dynamics and reproductive patterns of *Pyura tessellata* (Forbes) in Gulmarfjorden on the Swedish West Coast. Sarsia 67:249-257.

Upper Temperature Tolerance of two Antarctic Molluscs (*Laternula elliptica* and *Nacella concinna*) from Potter Cove, King George Island, Antarctic Peninsula

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Temperature is one of the most important environmental factors for marine invertebrates because they cannot maintain a constant body temperature. They are adapted to a species specific temperature range. High and low temperatures beyond this range cause death, the relation between mortality and temperature being sigmoid (Wolcott 1973). Thus, for stenothermal invertebrates, within a small temperature interval mortality increases from a low proportion to almost 100%. The best way to study and compare the temperature tolerance of different species and populations is the temperature causing 50% mortality (LT_{50}) a value, which lies within this interval.

Species are able to acclimate to slowly changing temperatures (seasonal changes) within a certain range and are adapted to the environmental conditions of their habitats. For example species of the North Sea can tolerate the normal annual variability of about 20°C (Arntz & Arancibia 1988) of this environment. In comparison, the Antarctic has a much more stable temperature regime (1 °C - 2 °C only). It can be assumed that the species adapted to these stable temperatures have little need for acclimation to changing temperatures and will be particularly sensitive to any temperature changes, e.g. in the case of global warming. However, little research regarding temperature tolerance of Antarctic invertebrates has been carried out so far.

In this study two dominant Antarctic shallow-water mollusks are to be compared. *Laternula elliptica* is a suspension-feeding infaunal bivalve found at depths between 5 - 25 m whereas *Nacella concinna* is a herbivorous gastropod of the intertidal and subtidal. The objectives are to compare the temperature tolerances of these two species. The following two hypothesis are presented:

1) The habitat of *Nacella concinna* is the intertidal where temperature variability is higher than in the deeper subtidal where *Laternula elliptica*

occurs. It is assumed that *Nacella concinna* is adapted to higher temperatures than *Laternula elliptica*.

2) In the study area two morphological forms of *Nacella concinna* are found. One, with more shallow shells is found in the subtidal whereas the second form is distributed more in the intertidal. Similar to Hypothesis 1 it is to be tested whether different temperature adaptations exist which would indicate the presence of two genetically different *Nacella concinna* populations.

Temperature tolerance experiments

The experiments were carried out at the Dallmann laboratory, a German-Argentinean annex station to the Argentinean station, Jubany (Potter Cove, King George Island, Antarctic Peninsula, 62°15' S, 58°44' W). Individuals were collected in the subtidal (10 m) by SCUBA divers or in the intertidal during low tide, at three sampling sites. Water temperature was recorded weekly at all sampling sites. From November '94 to February '95 temperature varied between -1.8 and 1°C.

For estimation of LT_{50}, subpopulations of 20 specimens (of 70 – 80 mm shell length) were placed in aquaria with different experimental temperatures (8°, 10°, 12°, 14°, 16°, 18° C). Temperatures were maintained constant (± 0.2°C) by electric heaters and sufficient oxygen concentration was obtained by aeration. After 24 h individuals were removed and stimulated mechanically to distinguish live from dead animals. Specimens showing no reaction were removed to cool water for a further 24 h to see if recovery took place, which however during none of the experiments was observed. For each temperature the experiments where repeated once and the mean of the two results calculated. Mortality (expressed as percentage of the mean of the original number present in the experimental aquaria with the same temperature) was plotted against experimental temperature (dosage-mortality approach, Urban 1994). A logistic curve (Eq. 1) was fitted to these data using an iterative non-linear least-square method (SIMPLEX algorithm, Press et al. 1986).

$$M = \frac{1}{\left(1 + e^{(B-C \cdot T)}\right)} \qquad (1)$$

where M is mortality [%], T is temperature [°C] and B and C are parameters of the equation. From Eq. 1 the LT_{50} (lethal temperature for 50% of an experimental subpopulation after 24 h) can be estimated with Eq. 2.

$$Lt_{50} = \frac{B}{C} \tag{2}$$

Very high temperatures cause death, however, also lower temperatures already have so called sublethal effects. An easy way to study this for infaunal bivalves is to test the ability of reburial into the substratum after being exposed to high temperatures. Reburial was studied by placing specimens, which had been exposed for 24 h to high temperatures (2°, 4°, 6°, 8°, 10°, 12° C) into aquaria filled with natural substrata, and flowing unfiltered seawater of 0°-1°C (ambient conditions). After 24 h the percentage of animals reburied into the substratum was recorded. Reburial was plotted against experimental temperature. A linear regression was carried out with logarithmic transformed temperature data and the reburial data (Eq. 3). The BT_{50} (temperature which inhibits 50% of an experimental subpopulation to rebury) was estimated from the inverse regression of Eq. 3.

$$R = a + b \bullet Ln(T) \tag{3}$$

where R is reburial [%], T is the temperature [°C] and a and b are parameters of the equation.

Because temperature tolerance depends on acclimation temperature (see introduction) normally the full tolerance potential is not detected if the LT_{50} only bases on one acclimation temperature. Therefore, a set of LT_{50} with animals acclimated to different temperatures has to be estimated, in order to study the full temperature tolerance potential. However, in the Antarctic, where water temperature variability is small, this does not apply: Fry et al. (1942, 1946) reported for 2 fish species a 1°C increase of the upper temperature tolerance for every 3°C to 7°C increase of the acclimation temperature. Thus, the acclimation temperature interval, which causes a change of the temperature tolerance in the Antarctic, is larger than the natural annual water temperature variability.

Statistical tests

The following two tests were applied to compare the mortality curves statistically.

Test 1: *Likelihood Ratio (LR) Test for mortality curves.* Ho: x(B, C) vs. Ha: y(B, C) is defined as:

$$\Lambda = \frac{\max l[x(B,C)]}{\max l[y(B,C)]}$$

with l(x) and l(y) being the corresponding likelihood functions and x(B, C) and y(B, C) are two mortality curves (Eq. 1) to be compared.

Test 2: *T^2-Test for equality of any mortality parameter.* The parameters B and C of the mortality curves are used to estimate LT_{50}. Therefore, to compare these parameters a further test is applied, i.e. to test the hypothesis:

$$H0: \frac{B_x}{C_x} = \frac{B_y}{C_y}$$

This hypothesis can be tested by using some of the asymptotic properties of the MLE of the parameters, provided that the normality assumption is true. In fact, under very general conditions the MLE are consistent, efficient and asymptotically normal. Then a joint test statistics for testing the hypothesis can be proposed: $T^2 = d' \bullet U^{-1} \bullet d$,

with $d = \frac{B'x}{C'x} = \frac{B'y}{C'y}$ and $U = U_1 + U_2, U_1 = Cov(B'_x, C'_x) U_2 = Cov(B'_y, C'_y)$.

To obtain Cov (B', C') the asymptotic standard errors of B' and C' and the asymptotic correlation matrix is used.

Table1: Results for temperature tolerance experiments of *L. elliptica* and *N. concinna.* (IT: intertidal, SL: subtidal)

a) LT_{50} and BT_{50} estimated graphically and with Eq. 2 and 3. B and C are the parameters of Eq. 1, a and b parameters of Eq. 3

b) Statistical comparison of mortality curves (Fig. 1) and parameters B and C of eq. 1. *LR-Test*: Likelihood-Ratio Test for equality of mortality curves, *T^2-Test* for equality of a parameter B or C. *: significant (p=0.05)

a)	Species	calculated	graph.	B	C	a	b
	L. elliptica (LT_{50})	14.9 °C	14.7°C	21.973	1.478		
	L. elliptica (BT_{50})	3.6°C	3.7°C			0.997	-0.912
	N. concinna (IT)	15.5°C	15.5°C	21.099	1.360		
	N. concinna (ST)	16.4°C	15.8°C	31.538	1.923		

b)	species comparison	*LR-*	*T^2-test*
	L. elliptica / N. concinna (IM)	*	*
	L. elliptica / N. concinna (SL)	*	*
	N. concinna (IM) / *N. concinna* (SL)	*	*

The LT_{50} and BT_{50} value(s) estimated from Eq. 2 and 3, as well as graphically are given in Table 1a. Table 1a also gives the parameters B and C of Eq. 1 as well as the parameters a and b of Eq. 3 used to plot the mortality and reburial curves. These curves are shown in Fig. 1. The LT_{50} lie about 15°C above the environmental temperature, *L. elliptica* having the smallest LT_{50} (14.9°C) followed by *N. concinna* (intertidal) (15.5°C) and *N. concinna* (subtidal) with the largest LT_{50} (16.4°C). The BT_{50} was estimated as 3.6°C. The two methods to estimate LT_{50} and BT_{50} (calculated and graphically) lead to very similar results.

The statistical results are given in Table 1b. The *Likelihood Ratio Tests* gave significant differences for all three mortality curve comparisons (p=0.05). The same result was obtained for the *T^2-Test*, which tested for equality of any of the two parameters.

Statistical tests confirm that the mortality curves and the LT_{50} are significantly different. Thus, the results corroborate the hypothesis presented: The intertidal*Nacella concinna* has a LT_{50} which is 1.5°C higher than the subtidal*Laternula elliptica*. This might be explained by the more stable temperature regime of the habitat of *Laternula elliptica*. Regarding temperature tolerance experiments on bivalves, it has been reported that often the temperature tolerance agrees with the distribution (Vasil'eva 1978) and can be related to zonation: Johnson (1965), Jansson (1967) and Ansell et al. (1980) observed that upper temperature tolerance decreased with increasing distance from shore. Apart from a horizontal distribution also vertical distribution has been taken into account. Wilson (1981) reported the upper depth limit of infaunal organisms buried in the substratum to be set by the upper temperature tolerance. All these arguments apply to this study: *Laternula elliptica* was collected at 10 m depth, compared to the intertidal *Nacella concinna*. Furthermore, *Laternula elliptica* is an infaunal species, buried up to 30 cm into the substratum, compared to the epifaunal *Nacella concinna*.

With respect to the second hypothesis, the subtidal *Nacella concinna* has a lower (0.9°C) LT_{50} than the intertidal *Nacella concinna*. As stated above, apart from this physiological difference, both populations also show morphological differences (shell shape). Further comparative investigations on both populations would be interesting.

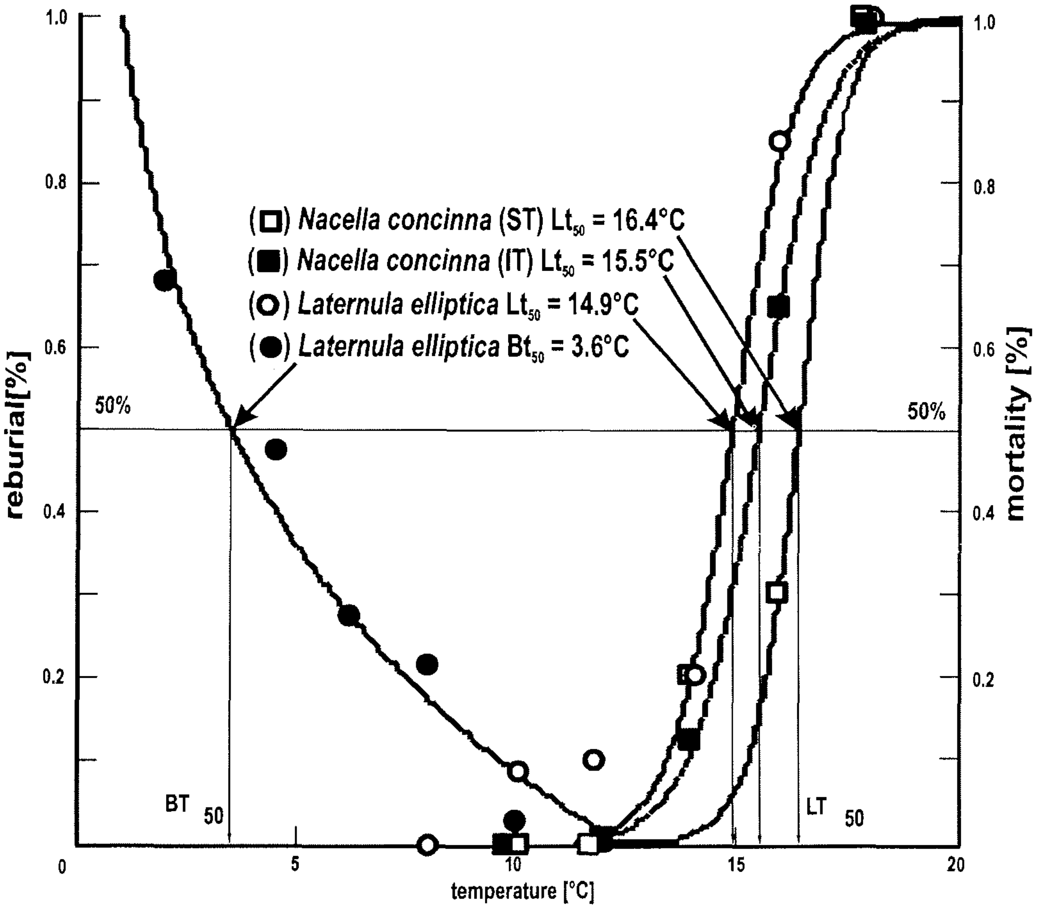

Fig. 1: Mortality - and reburial curves of *L. elliptica* and *N. Concinna.*
IT: intertidal, ST: subtidal

The LT_{50} results give the impression that the animals are well adapted regarding temperature increases. Temperature increases of 5°C - 10°C due to global warming are highly unlikely in the Polar regions in the near future. However, looking at the LT_{50} alone is misleading. The reburial experiments show that already temperature increases of 3 - 4°C affect 50% of the population physiologically. Such temperature increases are more likely to occur, indicating that the polar ecosystem then would be severely affected.

Literature Cited

Ansell, A. D., Barnett, P. R., Bodoy, A., Massé, H. (1980). Upper temperature tolerance of some European molluscs. I *Tellina fabula* and *T. tenuis*. Mar. Biol. 58: 33-39

Arntz, W. E., Arancibia, H. (1988). Fluctuaciones en el écosistema bentodemersal del Pacífico sur-oriental y el del norte de Europa: Una comparación. Memorias del Simposio Internacional de los Recursos Vivos y las Pesquerías en el Pacífico Sudeste, Rev. Pacífico Sur (Número Especial): 35-47

Fry, F. E. J., Brett, J. R., Clawson, G. H. (1942). Lethal limits of temperature for young goldfish. Rev. canad. Biol. 1: 50-56

Fry, F. E. J., Hart, J. S., Walker, K. F. (1946). Lethal temperature relations for a sample of young speckled trout (*Salvelinus fontinalis*). Univ. Toronto Stud. Biol.. Ser. 54; Publ. Ont. Fish. Res. Lab. 55: 1-35

Jansson, B. O. (1967). Diurnal and annual variation of temperature and salinity of interstitial water in sandy beaches. Ophelia 4: 173-201

Johnson, R. G. (1965). Temperature variation in the infaunal environment of a sand flat. Limnol. Oceanogr. 10: 114-120

Press, W. H., Flannery, B. P., Teukolsky, S. A., Vetterling, W. T. (1986). Numerical recipes. The art of scientific computing. Cambridge University Press, Cambridge

Urban, H.-J. (1994). Upper temperature tolerance of ten bivalve species off Peru and Chile related to El Niño. Mar. Ecol. Prog. Ser. 107: 139-145

Vasil'eva, V. S. (1978). Heat resistance of cells of upper sublittoral bivalve molluscs of sandy infauna in Peter the Great Bay (Sea of Japan). : 523-526

Wolcott, T. G. (1973). Physiological ecology and intertidal zonation in limpets (Acmaea): A critical look at "limiting factors". Biol. Bull. 145: 389-422

Wilson, J. G. (1981). Temperature tolerance of circatidal bivalves in relation to their distribution. J. Therm. Biol. 6: 279-286

Oxidative stress and temperature acclimation in Antarctic shallow water molluscs

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Oxidative damage in tissues of marine ectotherms is frequently related to elevated metabolic rates, i. e. under exercise, at elevated temperatures, and generally when the environmental conditions exert a physiological strain (hypoxia, hyperoxia, intoxication, UV-irradiation etc.) on an organism. If oxidative stress occurs, this may be due to increased metabolic liberation of reactive oxygen species or, on the other hand, to a dysfunction of the cellular antioxidant defence system. Oxidative stress is critical with respect to e. g. membrane integrity and may cause a disturbance of subcellular structures and of cellular homeostasis in general. Therewith, oxidative damage promotes cell death and eventually limits the survival of an animal under stressful conditions. For a general review of oxidative stress in cold environments see Viarengo et al. 1998. During the Jubany campaigns of 1995/96 and 1996/97 we studied the effect of increments of environmental temperature with respect to oxidative damage in intertidal and subtidal molluscs from Potter Cove.

Yoldia eightsi

Ventilation rates and oxygen uptake of the Antarctic bivalve *Yoldia eightsi* at 0.2 and 2.5 °C have been studied by Davenport (1988), who concluded both parameters to be independent of temperature alterations within the margins characteristic of the bivalves' subtidal Antarctic environment (-1.8 to 3°C). As it was our objective to investigate temperature induced oxidative stress, we included temperatures beyond the limits of environmental fluctuations (>3°C). Beginning at -1°C (in Potter Cove subtidal water temperatures vary between -1.3° and +1°C, Klöser et al. 1994) we measured the oxygen uptake of individual *Yoldia* specimens at 1° temperature increments up to 5°C. At this temperature we found the animals were starting to die.

Yoldia eightsi is a deposit feeder, which ingests sediment particles into the mantle cavity with the help of foot movements (Davenport 1988b). This seemingly energy consuming feeding mode is accompanied by periodic increases of the oxygen uptake and routine metabolic rate is characterized by an alternating pattern of high and low respiration rates. As our experiments were performed without sediment the vigorous foot movements observed may moreover reflect the attempts of the clams to burrow into the non-existing sediment. Fig. 1 compares „basal" or standard metabolic rate (SMR) and routine metabolic rate (RMR) of *Yoldia eightsi* between -1° and 5°C.

In accordance with Davenport (1988a) we found RMR and also SMR to be independent of temperature between 0 and 2°C. Beyond 2°C, i. e. outside the natural habitat temperature range, both rates increased progressively.

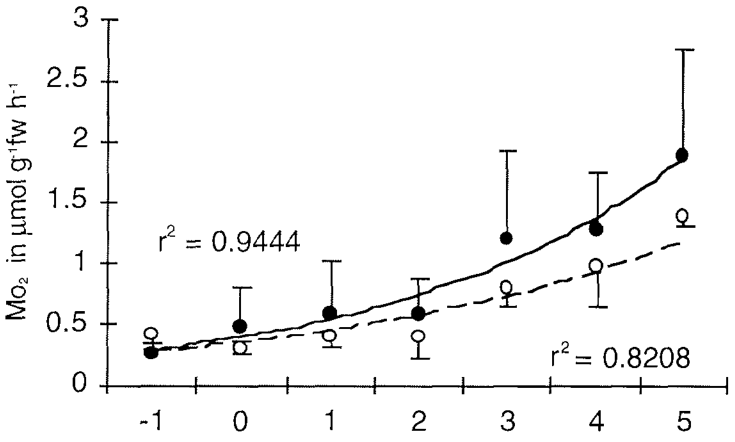

Fig.1: *Yoldia eightsi.* Specific metabolic rate (Mo_2) versus temperature. Black circles (●) depict RMR including phases of foot movements with elevated oxygen consumption. Open circles (○) depict baseline metabolism representing SMR (standard metabolic rate) of the animals. All data are normalized to tissue wet weight (n=5). Respiration was measured in a flow through respirometer (Eschweiler, Kiel) in which individual animals were incubated without sediment in filtered (2 µm) seawater from Potter Cove (34 o/oo) starting at -1°C and increasing the temperature by 1°C every 8-10 hrs. Of the total 8 hours interval at a given temperature, the first 2 hours were discarded as acclimation time.

Fig. 2 depicts the mean number of respiratory activity cycles per hour at different experimental temperatures and the respiratory volume, which was calculated from the number of respiratory cycles with elevated respiration per h multiplied with the mean absolute increase in oxygen consumption during active phases at the respective temperature. The absolute number of activity cycles per hour displayed an increasing trend towards higher temperatures. The high standard deviations are due to the fact that some animals showed no distinct activity pulses at all. Especially at -1 and 0°C the majority of the animals displayed more regular respiration and a relatively constant oxygen uptake over time. Thus, increasing numbers of activity pulses at 1°C already represents elevated locomotary activity. The respiratory volume increased progressively above 2°C, indicating a pronounced rise in energy expenditure. At 4°C the activity pulses were getting shorter indicating limitation of the aerobic capacity.

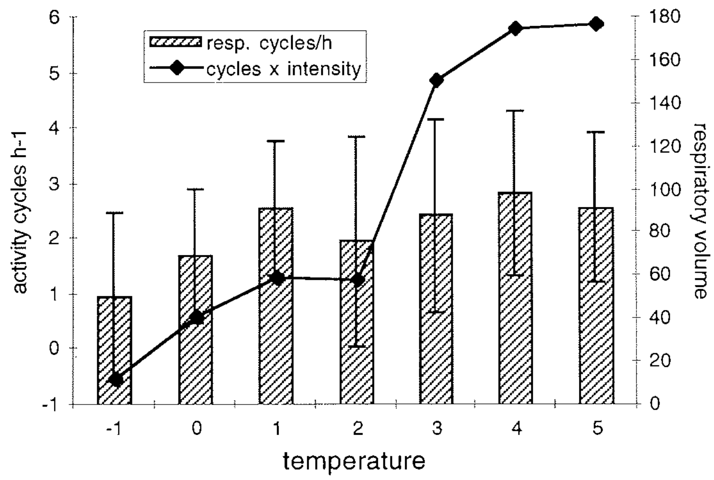

Fig. 2: *Yoldia eightsi*. Activity pulses versus temperature (n=5).

Significantly higher ATP concentrations ($p<0.001$) in foot muscle tissues were found in animals kept at 2°C as compared to both higher (5°C) and lower (0°C) temperatures (Fig. 3). There was no difference between animals exposed with and without sediment. Whereas the lower ATP levels at 0°C relate to the low metabolic rates, ATP concentrations at 5°C were reduced although Mo_2 was high. Presumably, ATP depletion in foot muscle indicates exhaustion of energy reserves at high temperatures. A concomittant onset of anaerobic metabolism appears likely and will characterize the critical temperature (see Pörtner et al. 1998), although data are as yet not available.

Elevated respiration resulted in a minor increase of malonedialdehyde (MDA) levels in gills of animals kept at 5°C compared to 0°C, whereas MDA levels were not increased in the foot. MDA is a common marker for lipid peroxidation resulting from oxidative tissue damage. The onset of oxidative stress at higher temperatures can also be delineated from an increase of the enzymatic antioxidant defence. Superoxide dismutase (SOD), which metabolizes superoxide radicals, displayed significantly higher activities ($p<0.001$, n=5-8) in animals exposed to 5°C over 48 hours (393 ± 57 U g^{-1} fw) as compared to 0°C controls (270 ± 17 U g^{-1} fw) and also compared to animals kept at 2°C over 48 hrs (215 ± 62 U g^{-1} fw). All assays were, however, conducted at 25°C and thus represent normalized activities. It can be inferred that real tissue activities at 2° and at 0°C are substantially lower. This may imply that tissue antioxidant defence in polar animals from permanently low temperature environments cannot be sufficiently increased, to effectively prevent oxidative damage during transient periods of elevated metabolic activity.

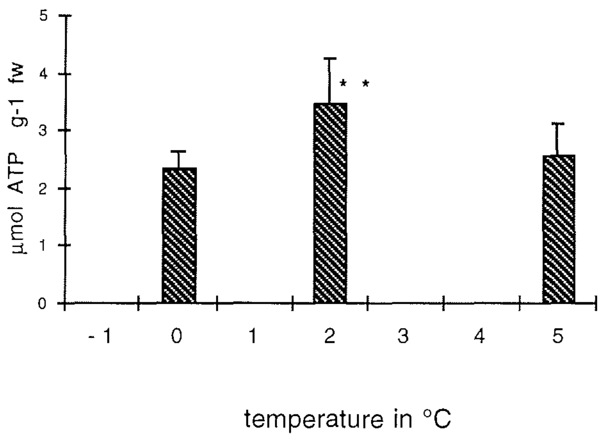

Fig. 3: *Yoldia eightsi.* ATP concentrations in foot muscle after temperature acclimation (8 hrs) to 0°, 2° and 5°C. Tissue ATP concentrations were measured at 0°C as well as after exposure to 2°C (16 hrs) and 5°C (20 hrs) in foot muscle tissue of animals kept in aquaria with sediment from the sampling location. A second group of animals was exposed to increasing temperatures in the respirometer (without sediment), following the same pattern of temperature increments as used in the respiration studies. As both treatments led to the same results, all data are combined in the above diagramm.

In conclusion: energetic exhaustion and elevated oxidative stress at 5°C are clues to the low critical temperature (T_c) of *Yoldia eightsi* (4-5°C), which is only slightly above the optimal temperature of 2°C. In contrast to other Antarctic bivalves (e. g. *Laternula elliptica* has a T_c of 9°C, Peck, Hardewig and Pörtner pers. comm.), *Yoldia eightsi* can well be termed „strictly stenothermal", which means that this species is confined to habitats of extremely constant, low temperatures.

Nacella concinna

The limpet *Nacella concinna* colonizes shallow subtidal habitats and displays maximal densities in shallow regions between 0 and 10m water depth in Antarctic coastal environments. Part of the population migrates to intertidal habitats in search for better feeding conditions during spring. It is not clear, whether the individuals migrate back and forth between the 2 habitats on a seasonal scale, spending spring and summer in the intertidal before returning to the subtidal in autumn, or whether part of the population, which migrates to the intertidal stays there for good and all.

Oxygen consumption in response to temperature increments of 1.5°C (in the range of -1.5°C to 9 °C) has been studied by Loyd Peck (1989) at Signy Island and we could fall back on his data concerning metabolic rates in our experiments. Peck found the animals were starting to die at temperatures higher than 9°C. For our experiments we kept to the range of viability (i.e. between 0 and 9°C). Acclimated Q_{10} values found by Peck were in the range between 0.8 and 3 over the whole T range studied. An exceptionally high Q_{10} of 20 was found for the temperature increment from 1.5° to 3 °C. Our study of oxidative damage and antioxidant protection was carried out with animals at a control temperature of 0° C and two groups of animals which had been acclimated to 4° and 9° over 48 hrs (in 2 steps for the 9° group). At temperatures above 0°, we found a progressive membrane destabilisation of the digestive gland lysosomal compartment, going together with increased accumulation of the aging pigment lipofuscin and an increased accumulation of neutral lipids. The activities of antioxidant enzymes were measured in gills (catalase) and in gills and hepatopancreas (SOD). Assays were carried out at the respective incubation temperature (0, 4 and 9°C) to delineate the real activity changes in limpet tissues at low temperatures. The tissue activities of both antioxidant enzymes increased from 0° to 4° and again to 9° C when measured at the respective incubation temperature, indicating that the elevated oxidative stress at higher temperatures elicits an increase of the animals´ antioxidant defence (Abele et al. 1998).

Combined stress of exposure to elevated H_2O_2 levels (4 μmol l^{-1}) and feeding was studied at 4°C. (Maximum natural H_2O_2-concentrations in tide pool water at King-George Island amounted to 2 μmol l^{-1}). Production of reactive oxygen species (ROS) increased in limpet tissues after exposure to H_2O_2 in fed and even more in starved limpets. Starved specimens had lower catalase activities in gills and showed a reduced ability to break down hydrogen peroxide in the incubation water, when compared to well fed animals (Abele et al. 1998).

Conclusive remark: Metabolic rates increase with temperature and cause an increased liberation of ROS in limpet tissues which can only partly be neutralized by an elevated antioxidant defence. ROS formation may, therefore, contribute to determine the upper critical temperature also in the case of limpets colonizing intertidal areas. Temperature induced oxidative stress is exacerbated by UV exposure, causing photooxidative ROS accumulation in tide pools that affect animals from outside and also induce a disturbance of basic metabolic functions. As nutrition seems to be crucial for the maintenance of an efficient antioxidant defence, negative effects of UV-B on algal primary production may lead into a vicious circle by limiting the food supply for animals in UV-exposed intertidal environments.

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Abele, D. B. Burlando, A. Viarengo, H. O. Pörtner (1998). Exposure to elevated temperatures and hydrogen peroxide elicits oxidative stress and antioxidant response in the Antarctic intertidal limpet *Nacella concinna*. Comp. Biochem. Physiol. B, in press.

Davenport, J. (1988a). Oxygen consumption and ventilation rate at low temperatures in the Antarctic protobranch bivalve mollusc *Yoldia (Aequiyoldia) eightsi* (Courthouy). Comp. Biochem. Physiol. 90A: 511-513.

Davenport, J. (1988b). Feeding mechanism of *Yoldia (Aequiyoldia) eightsi* (Courthouy). Proc. R. Soc. Lomd. B 232: 431-442.

Klöser, H., G. Ferreyra, I. Schloss, G. Mercuri, F. Laturnus, A. Curtosi (1994). Hydrography of Potter Cove, a small fjord-like inlet on King George Island (South Shetlands). Estuar. Coast. Shelf Sci. 38: 523-537.

Pörtner, H. O., Hardewig, I., Sartoris, F. J., van Dijk, P. L. M. (1998). Energetic aspects of cold adaptation: critical temperatures in metabolic, ionic and acid-base regulation?. In: Pörtner H. O.; Playle R. (eds.), Cold Ocean Physiology, Cambridge: Cambridge University Press; 1998: 88-120.

Viarengo, A., D. Abele-Oeschger, B. Burlando (1998). Effects of low temperature on prooxidants and antioxidant defence systems in marine organisms. In: H. O. Pörtner & R. Playle (eds.), Cold Ocean Physiology, Cambridge University Press, Cambridge: 213-235.

Studies on the lipoproteins of the Southern elephant seal *(Mirounga leonina)* during the breeding season at King George Island

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The Southern elephant seal *(Mirounga leonina)* is of great interest for physiological and biochemical studies of its dependence on lipid metabolism during periods of prolonged fasting. There is a strong evidence that the metabolic changes observed in this species are related to the ability to exist in the polar regions.

The annual life cycle of the adult Southern elephant seal includes two periods of terrestrial fasting. One is associated with breeding and the other with moulting (Laws, 1956a). These two fasting periods have different characteristics in terms of behaviour and energy requirements. During the breeding fast, the female must not only sustain their own metabolism, but has the additional energetic requirements of feeding the pup; major males ('beachmaster' and 'challenger') have additional energetic requirements of defending their positions in the harem hierarchy (Ling and Bryden, 1981).

The lactating female stays with her single pup until it is weaned some 23 days postpartum. With milk that contains up to 60% fat, the pups must accumulate energy reserves as blubber fat rapidly throughout the suckling period, while their mothers stay ashore and mobilise energy from stored reserves (Costa, 1991). After lactation has been completed, there is no further maternal care and weaned pups fast for 5-8 weeks on land. After 2-3 weeks of fasting, weaned pups move to coastal creeks, where they spend increasing amounts of time in shallow water before going to sea. The function and significance of this post-weaning fast is still unclear, but it might in some way be necessary for the development of diving and foraging abilities (Condy, 1979).

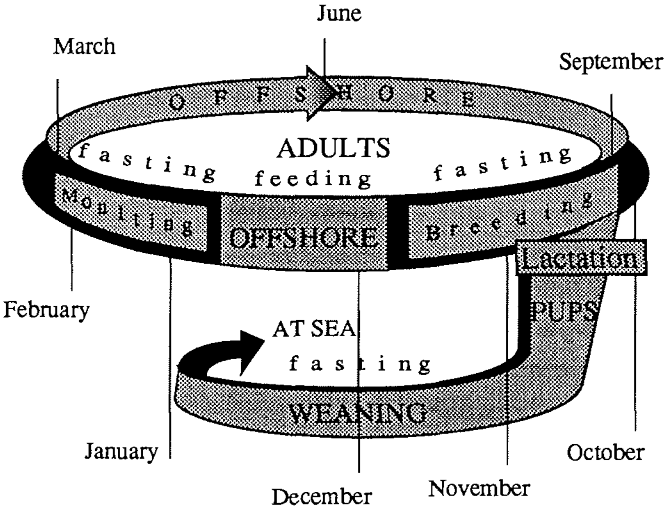

Fig. 1 The annual life cycle of the Southern elephant seal *(Mirounga leonina)* at its southernmost breeding distribution on King George Island.
Blood samples were collected from nursing females, their sucking pups, and from weaned pups.
Investigations on the 7-month-lasting offshore-period see Bornemann *et al.* this issue.

In the past, various data on the blood chemistry of Southern elephant seals have been reported (Castellini and Rea, 1992). The rapid transfer of energy as milk from mother to pup requires an increased capacity for catabolism in the mother and for anabolism in the pup. A large proportion of the weight gained by the pup is blubber (subcutaneous fat). The weaned pup, however, undergoes a conversion from blubber to mature tissue, especially those of muscles, nervous system, lungs and skeleton during the postweaning fast. Thus the reported data mainly concern values related to energy transfer and budget (Hindell *et al.* 1994). Lipoproteins are the carriers of metabolites such as triglycerides, phospholipids and cholesterol in the blood and have as such a central role in the processes of blubber deposition and mobilisation. Despite this, little is known about lipoproteins in pinnipeds. Puppione and Nichols (1970) suggested that the physical and chemical characteristics of lipoproteins changed significantly as the organism went through different alimentary stages. Dangerfield *et al.* (1976) noted that the lipid metabolism of marine mammals had attracted considerable interest since arteriosclerosis is rare in these animals despite the fact that their diet and milk is comparatively rich in fats and cholesterol. Schumacher *et al.* (1992) reported comparatively high cholesterol levels but low triglyceride levels in Weddell seals *(Leptonychotes weddellii)* when compared with humans.

The main aim of this study is to describe plasma lipoproteins and cholesterol in the Southern elephant seal, and the correlation between the reproductive cycle and the characteristic changes in the observed spectrum of lipoproteins and cholesterol. Whether the condition of the lipoproteins is involved in an expression of the specific adaptations to the polar environment will be considered. Another aim is to validate our method, which is derived from medical science.

Field studies were carried out from October 1995 to February 1996 and from September 1996 to March 1997 at Stranger Point, King George Island. (62°14'S-58°40'W).

The body weight and a total of 125 blood samples were obtained from 33 seals:

(1) 12 sampling profiles from randomly selected lactating cows and their pups with a maximum of 6 samples during the lactation (depending on whether cows finished lactation)

(2) 9 sampling profiles from randomly selected weaned pups with 5 samples during the weaning period (during the study period of 29 days).

Adult females were immobilised with ketamine hydrochloride (WDT®, Germany). The body weight was estimated, and the dosage was roughly calculated (Ryding, 1982). The solution was administered intramuscularly ($\bar{x}$= 3.44 mg/kg, SD=0.6) in the dorsal hip area using an automatic evacuating syringe (Göltenboth, 1988). Sucking pups and weaned pups were restrained manually with a bag.

The body weights of adults was obtained during immobilisation. Pups were weighed after being lifted manually. The blood samples were drawn from the extradural vein, cooled, and centrifuged (10 min, 4000 rpm). The serum was distributed both for immediate analyses and to storage in cryotubes (Nunc®, Germany) at -28°C for later examinations. In the field laboratory the *very low density lipoproteins* (VLDL, d<1.006 g/ml), *low density lipoproteins* (LDL, d=1.025-1.063 g/ml), and *high density lipoproteins* (HDL, d=1.063-1.21 g/ml) were isolated from the serum by analytical ultracentrifugation (BECKMAN® 100.3 Ti rotor, Palo Alto, CA) within 8 hours after being collected (Redgrave, 1975). Serum fractions from 4 randomly selected animals were isolated in a *fast protein liquid chromatography* (FPLC) column (Superose 6 HR 10/30, Pharmacia LKB®, Germany) based on Linton *et al.* (1995). Cholesterol (esterified and non-esterified) was measured photometrically in the serum (Boehringer®, Germany), both in the ultracentrifugally isolated lipoproteins, and in the 30 fractions derived from each FPLC procedure.

The findings were:

(1) Females lost an average of 29% of their initial body weight during lactation period. Their pups gained an average of 3.15 x their birthweight during lactation. Weaned pups lost an average of 27% of their body weight during weaning (Fig. 2a-c).

(2) Comparatively high cholesterol levels were found in females and weaned pups. During lactation, levels decreased in females, while rising from low levels in sucking pups and remaining steady in weaned pups (Fig. 3a-c).

(3) The HDL fraction (2 subclasses) was the predominant class at all ages.

(4) A relative redistribution of cholesterol between lipoproteins was noted during lactation (females and suckling pups), and in weaned pups (Fig. 4b, 5b, 6b).

(5) There was good agreement with respect to lipoprotein composition between the ultracentrifugation and the FPLC method (Fig. 4a, 5a, 6a)
The Spearman rank order correlation coefficient (r_S) and p is given in the figures.

The investigations reported are concerned with the lipoproteins, but they consider also the reliability of the methods used.

In the present work we used two methods for isolating lipoproteins, which are both descriptive. In the ultracentrifugation, lipoproteins are separated on the basis of molecular weight. In contrast, the FPLC method separates by molecular size. In both methods, we found a general agreement on cholesterol distribution in lipoproteins throughout the spectrum. Compared with humans, the cholesterol concentration is elevated. This is in contrast to many animals that have been investigated, especially mammals (Mills and Taylaur, 1971). However, most true carnivores, especially fish-eating marine mammals (Kaduce, 1981) greatly exceed normal cholesterol concentrations of humans (120–180 mg/dl). We are interested in why this is true for the Southern elephant seals; for example why do cholesterol levels in sucking pups increase by over 300% over a period of 23 days? We have to take account of the biochemical function of cholesterol on the one hand, and the seal‘s biology (e.g. diving, drastic feeding-fasting transitions) on the other.

Steroids derived from cholesterol with an antidiuretic effect, such as aldosterone, may enable fasting animals to conserve water in order to benefit the milk production

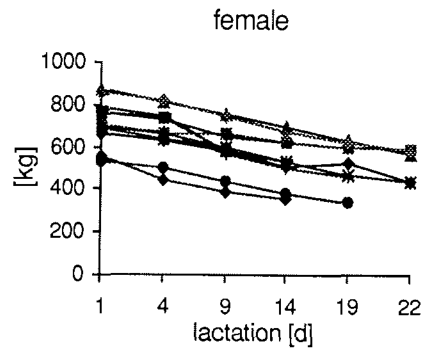

Fig. 2a Females lost 10.6 ± 2.9 kg/day ($\bar{X}$ ± SD; $r_S = -1.0$; $p < 0.05$; n=12).

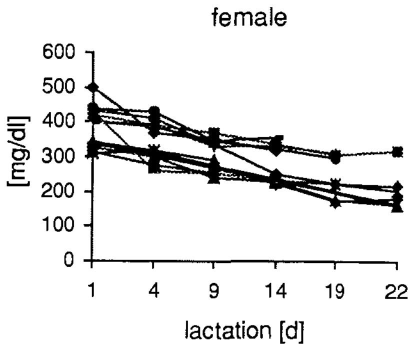

Fig. 3a Decrease in cholesterol concentration during lactation ($r_S = -1.0$; $p < 0.05$; n=12).

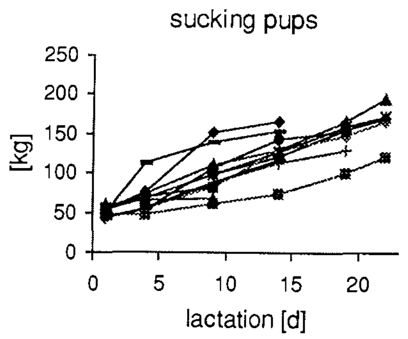

Fig. 2b Body weight gained 5.1 ± 1.0 kg per day ($\bar{X}$ ± SD; $r_S = 1.0$; $p < 0.05$; n=12).

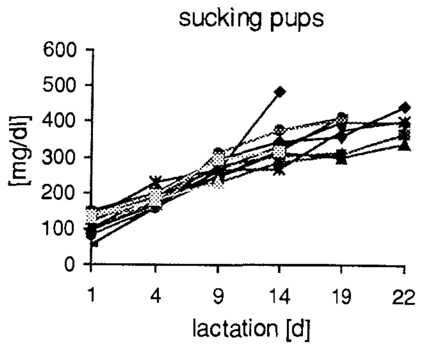

Fig 3b Increase in cholesterol concentration during lactation ($r_S = 1.0$; $p < 0.05$; n=12).

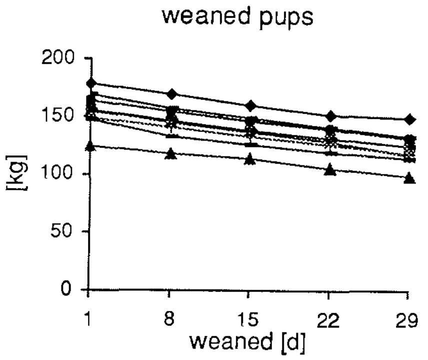

Fig. 2c Weaned pups lost 1.1 ± 0.14 kg per day ($\bar{X}$ ± SD, $r_S = -1.0$; $p < 0.05$; n=19).

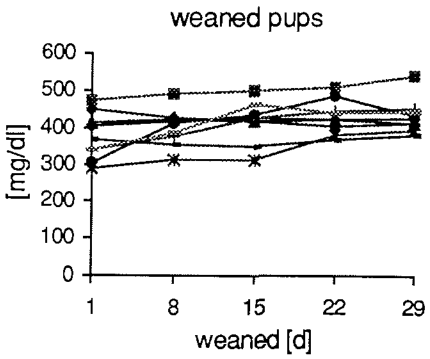

Fig. 3c Increase in cholesterol concentration during weaning ($p > 0.05$; n=9).

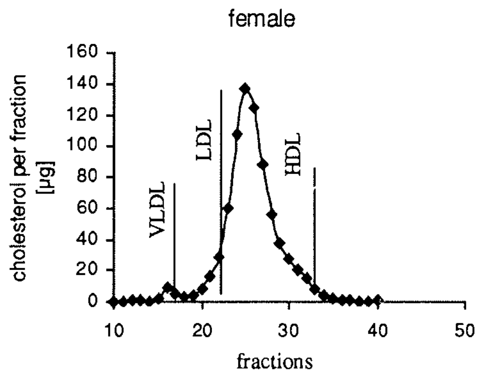

Fig. 4a FPLC-analysis at 1st day postpartum in a female, cholesterol appears mainly in the HDL fractions.

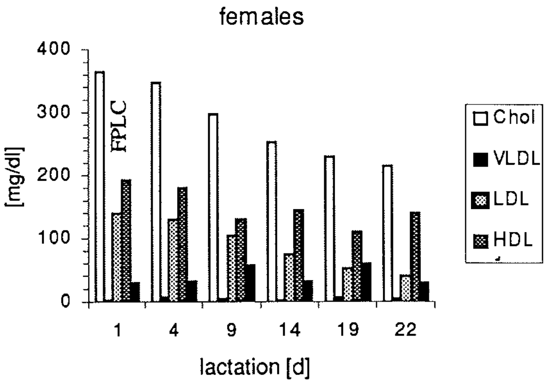

Fig. 4b Ultracentrifugal isolation of lipoproteins, cholesterol decreases, while HDL-cholesterol appears as the main fraction during lactation.

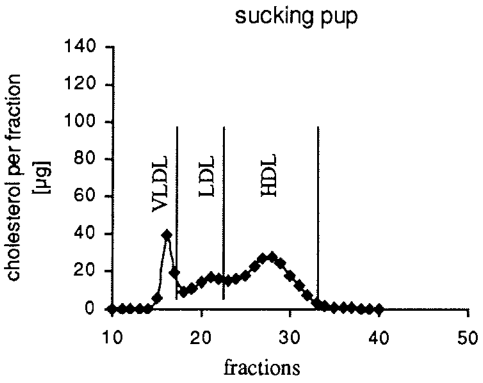

Fig. 5a FPLC analysis at 1st day postpartum in a pup. Cholesterol appears mainly in VLDL fractions, which is in contrast to the ultracentrifugal method (Fig. 5b)

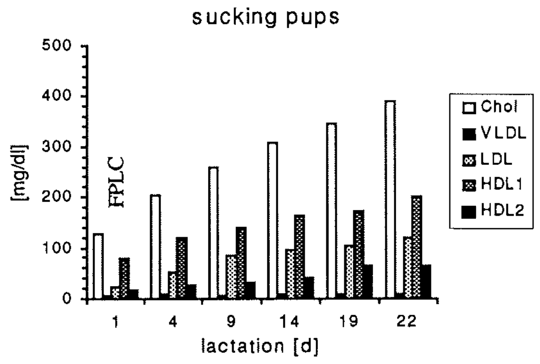

Fig 5b Cholesterol increases, while HDL-cholesterol appears as the main fraction during lactation.

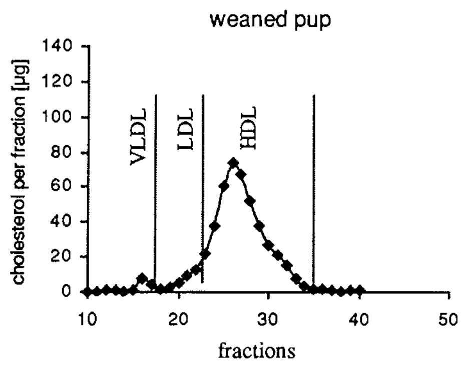

Fig. 6a FPLC analysis in a weaned pup at 15th day postweaning. Cholesterol has now shifted to the HDL fractions (compare Figg. 4a, 5a)

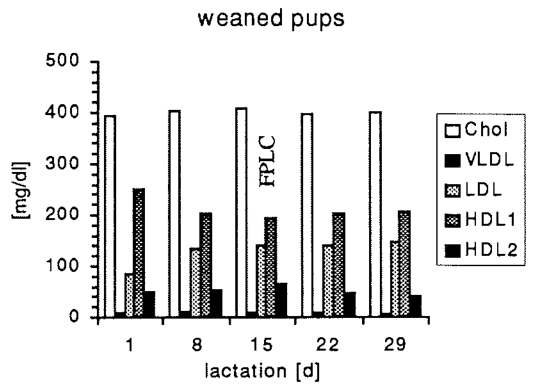

Fig. 6b Cholesterol distribution during the weaning period , HDL-cholesterol remains dominant

(females), the hydrolysis of triglycerides (lipolysis) in the blubber fat, and to compensate respiratory losses and water secreted into the gastrointestinal tract.

As cholesterol affects the fluidity of cellular membranes, it is conceivable that elevated levels of cholesterol may be required to strengthen endothelial cells in blood vessels against the hemodynamic and hydrostatic pressures that occur during deep dives approaching 1500m. The need to develop blood vessels in preparation for deep diving and migration to feeding grounds (Bornemann *et al.*, this issue) may explain why pups undergo the postweaning period ashore before departing to sea.

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Literature

Castellini M.A., Rea L. (1992) The biochemistry of natural fasting at its limits*; Experientia* (48) Birkhäuser Verlag, CH-4010 Basel/Switzerland

Condy P.R. (1979) Annual cycle of the southern elephant seal *Mirounga leonina* (Linn.) at Marion Island; *South African Journal of Zoology* 2:95-102

Costa D.P. (1991) Reproductive and foraging energetics of pinnipeds: implications for life history patterns; *in: Pinniped behaviour,* D. Renouf (Hrsg.) 1991, Chapman Hill

Dangerfield W.G., Finlayson R., Myatt G., Mead M.G. (1976) Serum lipoproteins and atherosclerosis in animals; *Atherosclerosis* 25:95-106

Göltenboth R. (1988) Zum aktuellen Stand der Immobilisation der Zootiere; *Deutsche Tierärztliche Wochenschrift* 95:402-403

Hindell M.A., Slip D.J., Burton H.R. (1994) Body mass loss of moulting female southern elephant seals, *Mirounga leonina*, at Macquarie Island; *Polar Biology* 14:275-278

Kaduce T.L., Spector A.A., Folk G.E. Jr. (1981) Characterisation of the plasma lipids and lipoproteins of the polar bear; *Comp. Biochem. Physiol. Vol* 69B:541-545

Laws R.M. (1956a) The elephant seal *(Mirounga leonina Linn.)* II. General, social and reproductive behaviour. *Falkland Islands Dependencies Survey, Scientific Reports* 13:1-88

Ling J.K., Bryden M.M. (1981) Southern Elephant Seal *(Mirounga leonina Linnaeus, 1758) Ridgeway/Harrison: Handbook of Marine Mammals,* Chapter 13:297-325

Linton M.F.,Atkinson J.B., Fazio S. (1995) Prevention of artherosclerosis in apolipoprotein E deficient mice by bone marrow transplantation (FPLC-methods); *Science* 267:1034-1037

McCann T.S, Rothery P. (1988) Population size and status of the Southern Elephant Seal *(Mirounga leonina)* at South Georgia; *Polar Biology* 8:305-309

Mills, G.L., Taylaur C.E. (1971) The distribution and composition of serum lipoproteins in eighteen animals; *Comp. Biochem. Physiol.* 40B:489-501

Puppione D.L., Nichols A.V. (1970) Characterization of the chemical and physical properties of the serum lipoproteins of certain marine mammals; *Physiol. Chem. & Physics* 2: 49-58

Redgrave T.G., Roberts D.C.K., West C.E. (1975) Separation of plasma lipoprotein by density gradient ultracentrifugation; *Analytical Biochemistry* 65:42-49

Ryding FN (1982) Ketamine immobilization of Southern Elephant Seals by a remote injection method; *Brit. Ant. Surv. Bull.* 57:21-26

Schumacher U., Rauh G., Plötz J., Welsch U. (1992) Basic biochemical data on blood from Antarctic Weddell Seals *(Leptonychotes weddellii).* Ions, Lipids, Enzymes, Serum proteins and thyreoid hormones; *Comp. Biochem. Physiol., Vol.* 102(3):449-451

Energy Investment in Pups of Southern Elephant Seals and Mass Changes in Females while at Sea at King George Island.

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Southern elephant seals have two periods of net energy loss. One of them is when they breed, the other when they moult. During both periods females fast, but during breeding they have an extra energy demand, since mothers not only sustain themselves but also their pups. These periods take place on land, which allows the direct measurement of mass, among other parameters. Additionally, they have two main periods at sea when they eat and store energy which will be used during breeding and moulting: one, between the end of lactation and moult and the other since the end of moulting until the next breeding period.

Females of southern elephant seals arrive to breed with the necessary energy reserves for lactation. This allows them some independence of local or time focalized changes in food availability, since they have already had about 8 months to build up these reserves (Costa et al. 1986; Costa 1991). Since females do not eat during breeding or moulting, mass changes can provide a useful comparative index of energy requirements or investment (e.g.Worthy and Lavigne 1987; Fedak and Anderson 1987), while the determination of body composition allows a much more accurate measurement of mass changes in terms of energy. Furthermore, mass changes of females while at sea give an approximate picture of their foraging success.

The breeding population of southern elephant seals at King George Island is situated in the southernmost distribution range for this species. Pregnant females haul out from the end of September to November, forming between eight and thirteen harems. Approximately 500 pups are born each season along about 6 km of coast. After breeding, females spend about two months at sea, coming back for moult since the middle of December to the end of January.

The present work brings together information collected during three field seasons on breeding energetics, body composition of pups, and mass changes in females while at sea and briefly compares it with that of other breeding groups. It presents information which has already been published and also work in the process of analysis and publication, and is a preliminary attempt to synthesize the information collected on this subject.

Mass transfer during breeding

Table 1 summarizes information collected during the 1994-1995 (Carlini et al. 1997) and 1996 breeding seasons on mass changes for sampled mother-pup pairs at King George. Females arrived to breed with a mean of 661± 120 Kg. During suckling they lost a mean of 10.70 ± 1.74 Kg/day. Larger mothers lost mass at higher rates than smaller ones. This was due not only to their greater absolute metabolic costs but also to the fact that they give more nutrients to their pups (Fig 1 and 2). Larger mothers also seem to suckle their pups for a longer period, since there was a weak correlation between the initial mass and the duration of the suckling period ($r= 0.45$, $df=37$, $P< 0.005$).

tab.1 Changes in mass in thirty-nine mother-pup pairs weighed during lactation at King George Island. The experimental period comprises the days between the first weighing (after parturition) and the second weighing (near weaning).

	Mean	S.D
Weight of females after parturition	661,2	120,2
Mass loss by females during experimental period	209,0	37,5
Weight of pups at birth	47,7	6,8
Mass gain by pups during experimental period	103,1	19,9
Weight of pups at weaning	157,3	27,3
Experimental period	19,5	1,4
Lactation period	22,6	2,2

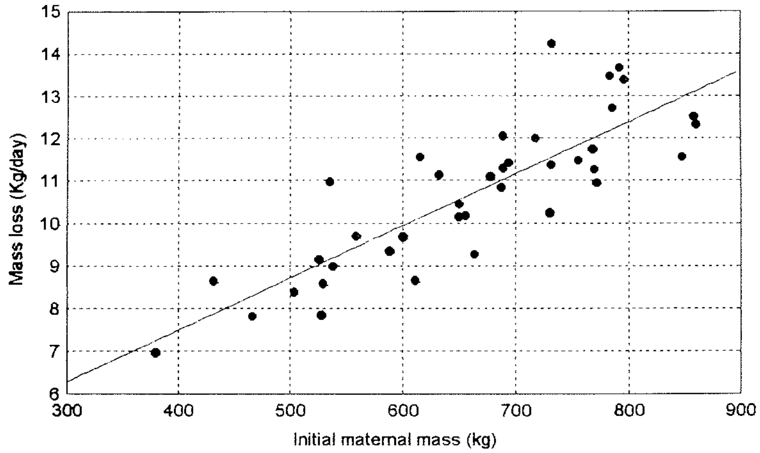

Fig. 1 Mass loss by females as a function of their weight at parturition.
Mass loss by females (kg)= 2.63 + 0.012 *Initial maternal mass (Kg). $F_{(1,37)}=88.7$, $P<0.001$, $r^2=0.70$

Pup growth rate was 5.3± 0.9 Kg/day. The weights of pups at birth and at weaning were positively related to the initial mass of their mothers: (r=0.60, df= 37, P < 0.001) and (r=0.78, df=37, P< 0.001) respectively. Pup growth rate was lower at the beginning of lactation and at the end of the suckling period (Fig 3).

There was a wide variation in mass after parturition for breeding females (379.5 - 858Kg), which presumably reflects differential maternal reserves. Since females fast during lactation, when they arrive for breeding they already have all the resources available to be passed to their pups. At South Shetland, maternal mass was strongly related to weaning mass, which is in agreement with previous results for South Georgia (McCann et al. 1989; Arnbom et al. 1993) and Península Valdés (Campagna et al. 1992).

Even though mean growth rate at King George is higher than that reported at South Georgia (McCann et al. 1989; Arnbom et al. 1993) the pattern of pup growth (Fig 3) is similar to that informed by McCann et al. (1989), being lower at the beginning and at the end of suckling than in the period in between these stages. This pattern can be related to that found in milk composition, which

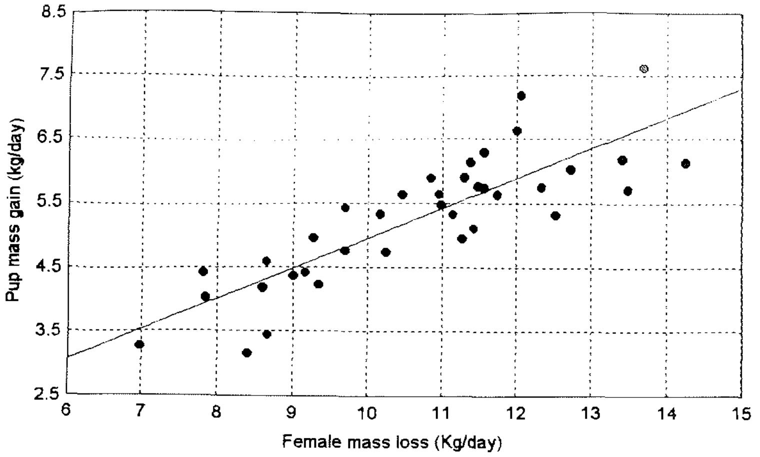

Fig. 2 Mass gain by the pups as a fuction of their mothers´ mass loss
Mass gain of pup (kg/day)= 0.26 + 0.47 * mass loss by their mother (kg/day). $F_{(1,37)}=88.4$, $P<0.001$, $r^2=0.70$

showed a low energy content at the beginning and at the end of the suckling period (Peaker and Goode 1978; Carlini et al. 1994; Hindell et al. 1994a), although the possibility of a differential rate of milk ingestion among the periods defined is not excluded.

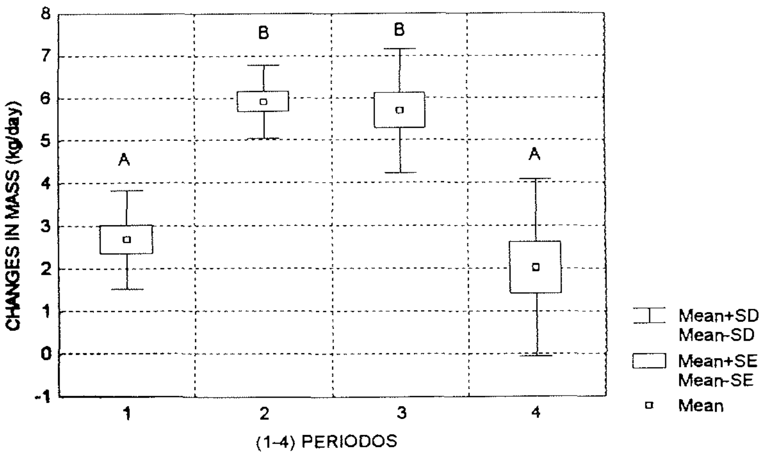

Fig. 3 Rate of mass gain by 12 pups taken sequentially during four periods during lactation. 1st. (0-4 days); 2nd(4-14 days); 3rd(14-19 days); 4th (19 to the end of lactation). To compare the mean values among periods, an ANOVA for repeated measures followed by a test for multiple comparison (Student - Newman Keuls method) was used. As a result, two groups with significant differences at $P<0.05$ were found: group (A) comprising the 1st and 4th periods and group (B) comprising the 2nd and 3rd periods.

Although southern elephant seals at King George Island belong to the same stock as those of South Georgia (Laws 1994, and bibliography therein) and seem to have similar mass transfer efficiency, females arrive for breeding with more reserves and are able to give their pups more nutrients during lactation than the females which breed at South Georgia (Carlini et al. 1997). Since females continue to increase their mass throughout life (Arnbom et al. 1994), it could be due to a difference in the average age of breeding females at both sites, as was suggested by Burton et al. (1997) as one of the possibilities to explain differences in pup weaning mass (from which differences in maternal mass were derived) found between breeding places situated in the Atlantic sector and those in the Pacific and Indian sectors. Another possible explanation could be that the greater mass of females at King George reflects higher growth rates throughout life. This fact would require that there should not be an important interchange between these close breeding places . Although females tend to give birth on the rookery where they were born, (Nicholls 1970) data on tracked females from South Georgia suggest that some interchange could take place (Ian Boyd pers. comm.) Long-term studies on marked animals at King George are needed to clarify the differences in maternal mass found between these breeding locations.

Pup body composition

Milk ingested by pups of southern elephant seals has a rich energy content, specially because of its high fat content (Bryden 1968a). Owing to the ingestion of such rich milk and to a permanent maternal attendance, pups can treble their birth weight in about 23 days of lactation. The energy stored during lactation is required immediately because pups undergo a post-weaning fast in which they draw mainly on their subcutaneous fat layer (Ortiz et al. 1978; Castellini et al. 1987; Rea and Costa 1992), which also acts as insulation from the high thermal conductance of water (Bryden 1968b).

At South Shetland, pups gain about 100 Kg during lactation and end the fasting period with approximately 70 % of their weaning mass. To measure mass changes in terms of energy and materials we have started to determine body composition in pups during the lactation and the fasting periods using isotope dilution techniques (Carlini et al. 1996; Carlini et al. in press). During the 1994/95 field season, body composition was determined in seven pups which were followed since they were born until a mean period of 36 days after weaning; additionally, 10 pups were taken only at weaning (Carlini et al. submitted A). Sampled pups were born with 49.8 ± 5.1 Kg and weaned with 162 ± 8.5Kg, n=7. The proportion of mass represented by fat was less than 2 % at birth, increasing to 35 ± 2%, n=7 at weaning. This represented a mean gain of 54 Kg of fat tissue during lactation. Energy reserved during this period was 2,437 Mj. Mass represented by fat at weaning was correlated with body mass at weaning Fig. 4. During the fasting period measured, pups used about 39% of the total energy gained while suckling. Considering that pups fast for a mean period of 45 days (Arnbom et al. 1993), the total energy used would be approximately 50% of that gained while suckling. Mass at birth and mass at weaning were significantly greater than those reported at Macquarie Island (Hindell et al. 1994a), showing no significant differences in the percentage of mass represented by fat. Because of the difference in weight at weaning for both populations, pups at South Shetland are weaned with about 20% more fat reserves. The greater mass at weaning allows pups at South Shetland to end the fasting period with greater reserves, which could be important for survival in their first stage of nutritional independence at sea.

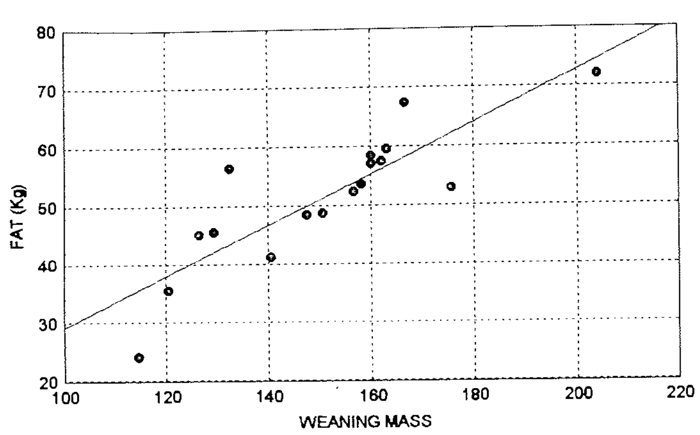

Fig. 4. The relationship between weaning mass (Kg) and fat mass at weaning (Kg). Fat mass at weaning = -14.35+0.44*weaning mass. $F_{(1,15)}$=38.9, P<0.001, r^2=0.72

Mass gain while at sea

When females leave the beach after lactation they are about 35 % lighter than when they arrived for breeding. At this time, they begin an intensive foraging phase which precedes a new fasting period on land during moulting.

Measurements of mass gain during the foraging period between the end of lactation and moult were taken from 12 females during 1995/96 (Carlini et al. 1997) and from 6 females during 1996/97 (Carlini et al. submitted b). Overall, females spent 59.1 ± 6.4 days at sea and gained a mean of 127.7 ± 34.7 Kg (Table 2).

tab.2 Time spent and mass gained by females while at sea between the end of lactation and the beginning of moulting for two different years.

	1995/96 (n= 12) Mean ± SD	1996/97 (n=6) Mean ± SD	t-test
Time spent at sea between lactation and moulting (days)	60,5 ± 6,2	57 ± 6,0	ns
Mass gained (kg)	132,2 ± 35,6	118,8 ± 34,0	ns
Rate of mass gained (kg/day)	2,21 ± 0,65	2,14 ± 0,72	ns

ns, non significant at P > 0,05

There was a positive correlation between the departure date at the end of lactation and the day of return to moult for 1995/96 (r= 0,73, df=10, P< 0,05) and 1996/97 (r= 0,90, df= 4, P< 0,05), The success during the foraging period was widely variable (88 to 204 Kg) and was not related to size at the end of lactation, or to time spent at sea, suggesting that foraging success can be related especially to individual abilities,There was no significant difference in time spent at sea or in mass gained between the years (Table 2), However, the sample is small and three females which were recaptured in both seasons showed a lower mass gain in 1996/97 (mean=125 Kg, S,D,=44) than in 1995/96 (mean=153 Kg, S,D,=44) (Paired t-test P= 0,009) , which could indicate less food availability during the former season,

As a mean, females recovered 54 % of the mass lost while breeding, Compared with other breeding groups, females at King George gained more mass and employed less time at sea between lactation and moult than those informed for South Georgia (Boyd et al, 1993), a fact which can be related to shorter distances to foraging areas,

During the second period at sea, since the end of moulting to the weighing carried out after parturition in the next breeding season, five females which were recaptured showed a rate of mass gain of 1,12 ±0,26 kg/day during a mean period of 253 ±3,7 days (Carlini et al, submitted b), The rate of mass gain during this period at sea was lower than that between the end of lactation and moulting, Nevertheless, females were 8,6 ± 5,0% greater when they arrived for breeding as compared with the previous season,

Mass lost by females during moulting

The data on weight changes during moulting included below constitute an interim presentation of information, It is included here to complement the data on the rest of the annual cycle of females of southern elephant seals, The moult of southern elephant seals takes place on land and involves the replacement of hair and the top layers of the epidermis (Ling 1968), During this period females fast, so the cost of the new integument must be covered from their reserves,

At King George, females begin to arrive for moulting in the middle of December and reach the peak number at about the end of January, During 1995 and 1996, nine females were followed during moulting (Carlini et al, submitted b), Since females frequently move into the water and sometimes move to other sites, it is difficult to measure the duration of the moulting period exactly, The mean period measured at King George was 25 ± 4,2 days, The initial mass at moulting was 567 ± 73 Kg, The rate of weight loss (5,0 ± 0,4 Kg/day) was not significantly different from those reported at South Georgia (Boyd et al, 1993) and Macquarie Island (Hindell et al, 1994b),(ANOVA, F=2,12, P=0,13), However, the moulting period measured at King George was longer and females lost a mean of 27% and 43% more mass than at South Georgia and Macquarie Island respectively, This difference may be due to their greater mass at arrival, which would result in higher absolute costs, and also to the longer period measured at King George Island,

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References

Arnbom T,, Fedak M,, Boyd I,L,, Mc Connell B,J, (1993), Variation in weaning mass of pups in relation to maternal mass, postweaning fast duration, and weaned pup behaviour in southern elephant seals (*Mirounga leonina)* at South Georgia, *Canadian Journal of Zoology 71*, 1772-81,

Arnbom T,, Fedak M,A,, Rothery, P, (1994), Offpring sex ratio in relation to female size in southern elephant seals, *Mirounga leonina, Behav, Ecol, Sociobiol, 35*: 373-378, Boyd I,L,, Arnbom T,, Fedak M, (1993), Water flux, body composition, and metabolic rate during molt in female southern elephant seals (*Mirounga leonina), Physiological Zoology, 66* (1), 43-60,

Burton H,R,, Arnbom T,, Boyd I,L,, Bester M,, Vergani D,, Wilkinson I,(1997), Significant differences in weaning mass of southern elephant seals from five sub-Antarctic islands in relation to population declines, In : Battaglia B,, Valencia J,, Walton D,W,H, (eds) Antarctic Communities : Species, structure and survival, Univ, press, United Kigdom, pp 335-338

Bryden M,M, (1968a), Lactation and suckling in relation to early growth of southern elephant seal, *Mirounga leonina* (L,), *Aust, J, Zool,16*: 739-748,

Bryden M,M, (1968b), Growth and function of the subcutaneous fat of the elephant seal, *Nature 220*, 597-9,

Campagna C,, Le Boeuf B,J,, Lewis M,, Bisioli C, (1992), Equal investment in male and female offpring in southern elephant seals, *J,Zool, (Lond), 226*: 551-561,

Carlini A,R,, Daneri G,A,, Márquez M,E,I,, Soave G,E,, Poljak S, (1997), Mass transfer from mothers to pups and mass recovery during the post-breeding foraging period in southern elephant seals (*Mirounga leonina)* at King George Island, *Polar Biol, 18* (5), pp 305-310,

Carlini A,R,, Márquez M,E,I,, Daneri G,A,, Panarello H,O,, Ramdohr S, (in press), Inversión maternal en el elefante marino del sur en la Isla 25 de Mayo, Antártida, Proceedings of the Cuartas Jornadas sobre Investigaciones Antárticas, Buenos Aires, Argentina, September, 1997,

Carlini A,R,, Márquez M,E,I,, Daneri G,A,, Poljak S,(submited B), Mass changes during their annual cycle in females of Southern elephant seals at King George Island

Carlini A,R,, Márquez M,E,I,, Soave G,E,, Vergani D,F,, Ronayné de Ferrer P,A, (1994) Southern elephant seal, Mirounga leonina: Composition of milk during lactation, *Polar Biology, 14* :37-42,

Carlini A,R,, Panarello H,O,, Márquez M,E,I, (1996) Ganancia y pérdida de energía en cachorros de elefante marino del sur durante la lactancia y el ayuno postdestete, Abstract from the 7ma Reunión de Trabajo de Especialistas en Mamíferos Acuáticos de América del Sur y 1er, Congreso Lationoamericano de Especialistas en Mamíferos Acuáticos, Viña del Mar, Chile, October, 1996,

Carlini A,R,, Panarello H,O,, Márquez M,E,I,, Soave G,E,, Daneri G,A, (submitted A), Energy gain during lactation and subsequent energy loss by the weaned pup in the Southern elephant seal (*Mirounga leonina),*

Castellini M,A,, Costa D,P,, Huntley A,C, (1987), Fatty acid metabolism in fasting elephant seal pups, *J, Comp, Physiol,B, 157*:445-449,

Costa D,P, (1991), Reproductive and foraging energetics of pinnipeds, In: Renouf D, (ed,) The behaviour of pinnipeds, Chapman and Hall, London, pp, 300-344,

Costa D,P,, Le Boeuf B,J,, Ortiz C,L,, Huntley A,C, (1986) The energetics of lactation in the northern elephant seal, *J, Zool, Lond, 209*: 21-33,

Fedak M,A, and Anderson S,S, (1987), Estimating energy requirements of seals from weight changes, In Huntley A,C,, Costa D,P,, Worthy G,A,J,, Castellini M,A, (eds), Marine Mammal Energetics, Society for Marine Mammalogy, Lawrence, pp 205-226,

Hindell M,A,, Bryden M,M,, Burton H,B, (1994a), Early growth and milk composition in Southern elephant seals (*Mirounga leonina*), *Aust,J, Zool, 42*, 723-32,

Hindell M,A,, Slip J,S,, Burton R, (1994b), Body mass loss of moulting female southern elephant seals, *Mirounga leonina*, at Macquarie Island, *Polar Biol, 14*: 275-278,

Laws R,M, (1994) History and Present Status of Southern elephant seal populations, In B,J, Le Boeuf and R,M, Laws (eds) Elephant seals Population Ecology, Behavior and Physiology, University of California Press, Berkeley and Los Angeles pp 49-65,

Ling J,K, (1968), The skin and hair of the Southern elephant seal, *Mirounga leonina* (L,), III, Morphology of the adult integument, *Aust, J, Zool, 16*: 629-645,

Mc Cann T,S,, Fedak M,A,, Harwood J, (1989), Paternal investment in southern elephant seals, Mirounga leonina, *Behaviour Ecology and Sociobiology 25*, 81-/,

Nicholls D,G, (1970), Dispersal and dispersion in relation to birth site of southern elephant seal, *Mirounga leonina* (L,), of Macquarie Island, *Mammalia* 34: 598-616,

Ortiz C,L,, Costa D,P,, Le Boeuf B,J, (1978), Water and energy flux in elephant seal pups fasting under natural conditions, *Physiological Zool, 51*, 166-77,

Peaker M, and Goode J,A, (1978) The milk of the fur seal *Arctocephallus tropicalis gazella:* in particular the composition of the aqueous phase, *J, Zool, 185*: 469-476,

Rea L,D, and Costa D,P, (1992), Changes in standard metabolism during long-term fasting in northern elephant seal pups (*Mirounga angustrirrostris), Physiol, Zool, 65*: 97-111

Worthy G,A,, and Lavigne D,M, (1987), Mass loss, metabolic rate and energy utilization by harp and gray seal pups during the postweaning fast, *Physiological Zoology 60*: 352- 364,

4. FOOD WEB STRUCTURE AND ENERGY FLOW IN THE ECOSYSTEM

Trophic relations between macroalgae and herbivores

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The coastal area of the outer Potter Cove and adjacent regions are characterized by a dense and rich macroalgal flora. These algae contribute to the food resources of the shallow water ecosystem, either as already degraded organic material or as fresh algae. Huge amounts of algae are degraded, until they are a suitable food resource for benthic organisms. Detached algae can be decomposed by biological and hydrodynamical processes and some may drift into deeper waters to provide food for benthic deposit and suspension feeders. The significance of living macroalgae as food for invertebrates and demersal fish in the Antarctic marine ecosystem, however, is less well understood.

The importance of trophic relations between macroalgae and herbivores in Potter Cove was investigated, focusing on three major questions:
1) Which herbivores are feeding on living macroalgae and do they show specialisation or preference for certain algal species?
2) Do Antarctic macroalgae exhibit defensive properties to avoid herbivore grazing?
3) Which order of magnitude is the consumption of herbivores grazing on macroalgae?

Herbivorous (or partly herbivorous) animals feeding on fresh macroalgae in the Potter Cove comprise gastropods, amphipods, polychaetes, isopods, and fish (Iken 1996).
Among the herbivores specialists and generalists can be distinguished. Specialists, feeding only on a small number of macroalgal species, are e.g. the limpet *Nacella concinna* and the isopod *Plakarthrium punctatissimum. N. concinna* is mainly specialized on crustaceous red algae and the brown alga *Ascoseira mirabilis*, while *P. punctatissimum* particularly feeds on the red alga *Curdiea racovitzae* and the brown alga *Ascoseira mirabilis*. Other herbivores, such as the gastropod *Laevilacunaria antarctica*, the amphipod *Gondogeneia antarctica*, or the fish *Notothenia coriiceps* are generalists and graze on a large variety of algal species (Fig. 1).

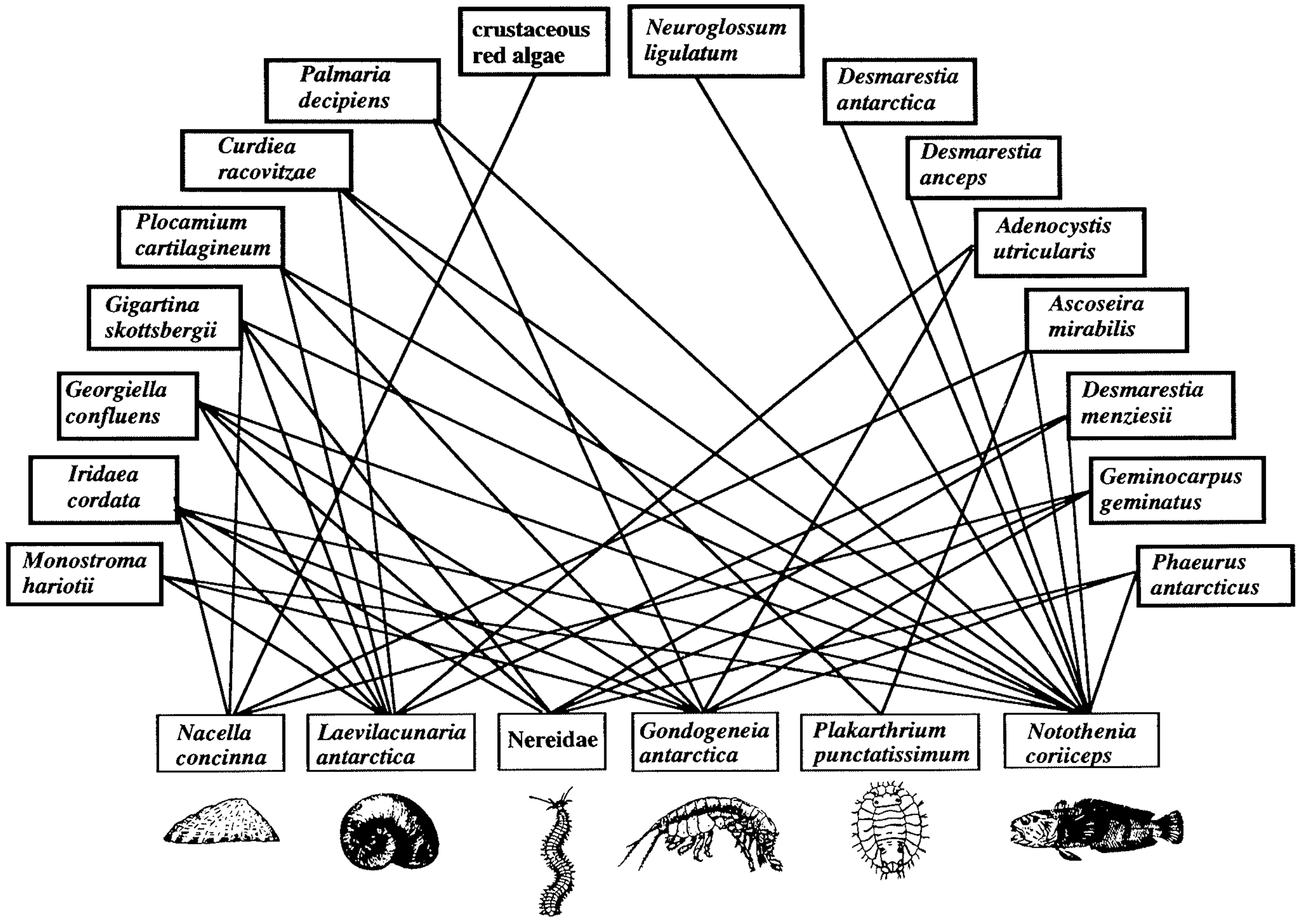

Fig.1: Trophic relationships between herbivores (below) and macroalgae (above). Each connecting line characterizes that the herbivore is feeding on the alga.

Detailed investigations were conducted to elucidate the complexity of feeding interactions between macroalgae and the abundant demersal fish *Notothenia coriiceps* (Iken et al. 1997). Eighteen algal species contribute to the diet of the fish in a mean proportion of nearly 40% by weight. These algae include two chlorophytes, ten rhodophytes and six phaeophytes, with *Monostroma hariotii*, *Palmaria decipiens* and *Desmarestia menziesii* comprising the greatest portions of algal biomass, respectively.

The "Linear Food Selection Index L" (Strauss 1979) was applied to investigate whether *N. coriiceps* selects actively among the algal species available, i.e. if distinct algal species are preferred or avoided food items, a question which has been subject to discussion in the literature for several years (Moreno & Zamorano 1980, Barrera-Oro & Casaux 1990). Among the algal species ingested, *Palmaria decipiens* (Rhodoph.), *Monostroma hariotii* (Chloroph.), *Desmarestia menziesii* (Phaeoph.), and *Iridaea cordata* (Rhodoph.) were significantly preferred, whereas *Himantothallus grandifolius* and *Desmarestia anceps* (both Phaeoph.) were significantly avoided compared to their availability in the benthos. For the remaining algal species investigated, neither preference nor rejection was detected, i.e. *N. coriiceps* is indifferent with respect to those species. Preference or avoidance of algal species are not related to the amount of associated epifauna (e.g. amphipods) to the algae. We concluded that *N. coriiceps* ingests macroalgae as proper food items and not only accidentally while preying on invertebrates.

Detailed histological investigation of algal species from fish stomach contents confirmed that *N. coriiceps* frequently feeds on some very shallow water algal species, such as the red alga *Porphyra endiviifolium* (Iken et al. subm.). This species occurs in the eulittoral only, hence its accessibility to fish is usually supposed to be very low. We suggest that *N. coriiceps*, which mainly inhabits coastal waters down to 50 m depth, is able to migrate to extremely shallow waters for feeding, what hitherto has been unknown.

Some algal species are frequently ingested by herbivores while others are rarely or never found as food items. It therefore has been subject of our investigation whether Antarctic macroalgae are protected against animal feeding, particularly considering the nutritional value, chemical defense, and physical features such as thallus toughness. The nutritional state of macroalgae was characterized by their carbon/nitrogen (C/N) values and ash contents. Mean C/N ratios of all investigated algal species ranged between six and ten, which is low compared to ratios of temperate and tropic species. Low C/N values of the Antarctic macroalgae are due to high amounts of aminoacids and proteins (Weykam et al. 1996). The low C/N ratios as well as low ash contents stand for a high nutritional value and probably reflect the high inorganic nitrogen supply in Antarctic waters.

Extracts of macroalgae have been analysed for secondary metabolites which may exhibit defensive properties. Polyphenolics, which are known to deter animals from grazing in temperate brown algae, were detected in several brown algae (e.g. *Adenocystis utricularis*, *Phaeurus antarcticus*, *Himantothallus grandifolius*). Feeding assays with extracts of the respective brown algae and the general herbivore gastropod *Laevilacunaria antarctica* did not show any effect of the polyphenolics as feeding deterrents (Fig.2). Moreover, the feeding experiments proved that physical properties, e.g. the toughness of the algal thallus, are the more likely factors to prevent herbivores from grazing.

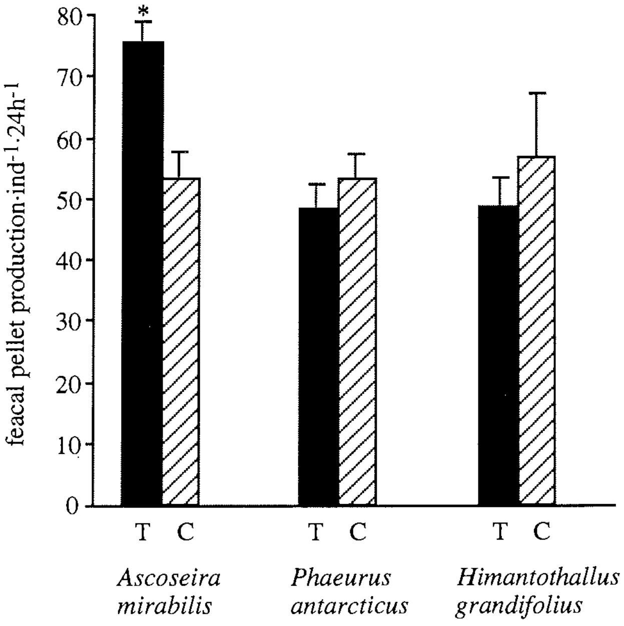

Fig.2: Feeding assay with the herbivore gastropod *Laevilacunaria antarctica* grazing on artificial food cubes: Feacal pellet production when feeding on cubes containing polyphenolic extracts of brown algae (T, dark bars) was not significantly lower than feeding on control cubes (C, light bars). Grazing on test cubes of *Ascoseira mirabilis* was significantly higher ($p<0.001$).

A first assessment to evaluate the input and effect of herbivore grazing on the macroalgal community has been made by quantification the consumption of the herbivorous gastropod *Laevilacunaria antarctica*. Consumption of different size classes of snails was determined for the most abundant macroalgae in feeding experiments. Considering a mean abundance of *L. antarctica* of 292 ind·m^{-2} (S.D.=135.32) in the rocky intertidal of Potter Cove, mean consumption is computed to be 37.6 mg DW algae·m^{-2}·d^{-1}, which sums up to an annual consumption of 9 g DW algae·m^{-2}·y^{-1}. This estimated total consumption of macroalgae is comparatively low, but the overall impact of grazing on algae or the algal community might be considerable because of the damage of physiologically sensitive or reproductive tissues. More severe effects may also be found due to the feeding of larger herbivores such as fish or echinoderms, which has to be subject to future studies.

The trophic pathways between macroalgae and herbivores in Potter Cove exhibit rather complex interactions. They have to be considered as long-term established and non-casual predator-prey interactions.

References

BARRERA-ORO, E.R. & CASAUX, R.J. 1990. Feeding selectivity in *Notothenia neglecta*, Nybelin, from Potter Cove, South Shetland Islands, Antarctica. *Antarctic Science*, **2**, 207-213.

IKEN, K. 1996. Trophic Relations between Macroalgae and Herbivores in Potter Cove (King George Island, Antarctica). *Berichte zur Polarforschung*, **201**, 1-206. [in German]

IKEN, K., BARRERA-ORO, E.R., QUARTINO, M.L., CASAUX, R.J. and BREY, T. 1997. Grazing by the Antarctic fish *Notothenia coriiceps*: Evidence for selective feeding on macroalgae. *Antarctic Science* , **9** (**4**), 386-391.

IKEN, K., QUARTINO, M.L. and WIENCKE, C. (subm.). Histological identification of macroalgae from stomach contents of the Antarctic fish *Notothenia coriiceps* gives new insights in its feeding ecology. *Marine Ecology*

MORENO, C.A. & ZAMORANO, J.M. 1980. Séleccion de los alimentos en *Notothenia coriiceps neglecta* del cinturon de macroalgas de Bahía South Antarctica. *Ser. Cient. INACH*, **25-26**, 33-43. [In Spanish]

STRAUSS, R.E. 1979. Reliability estimates for Ivlev's Electivity Index, the Forage Ratio, and a proposed Linear Index of Food Selection. *Trans. Am. Fish. Soc.*, **108**, 344-352.

WEYKAM, G., GÓMEZ, I., WIENCKE, C., IKEN, K. and KLÖSER, H. (1996). photosynthetic characteristics and C:N ratios of macroalgae from King George Island (Antarctica). *J. Exp. Mar. Biol. Ecol.*, **204**, 1-22.

Studies on Krill from Penguin Stomach Contents at Potter Cove

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Samples of stomach contents of adelie penguins are routinely obtained as part of the CCAMLR Ecosystem Monitoring Program, with the primary aim of studying food composition of penguins as an auxiliary tool for the analysis of penguin data. Secondarily, individual krill from these samples are routinely measured (total length, carapace length, uropods and telson). Krill data are used as a convenient source of information on local krill populations (whithin the feeding range of penguins).

In a previous study (Marschoff and González, 1992) we replicated samples obtained from individual penguins and demonstrated that penguins do not feed selectively. This means that krill obtained from stomach contents of penguins is not selected at the individual bird level and that penguins behave homogeneously with regard to the size of their food.

Stomach contents might be considered as random samples of the fraction of krill population eaten by penguins (analogous to treating net samples as representative of the fraction of the population available to nets).

The spatial structure of the krill population is reflected in differences in samples of krill sizes obtained from different penguins at the same time. Time variations in the population of krill will also be "seen" in the stomach contents as differences in samples obtained at different times.

While net samples can be referred (at least implicitly) to a sampling frame, where all possible sample locations are associated with a probability of being sampled; penguin stomach contents are obtained through a feeding process not easily modelled in a probabilistic framework.

A complete analysis of "penguin food" can be carried out on the available data, but the extrapolation of the results to the krill population requires information and assumptions on the feeding process (search methods, cooperation between penguins, repletion, etc.) of penguins. Since nor the model nor the assumptions have yet been defined, we restrict our analysis to "penguin food" for the time being.

The analysis of the mean size of krill eaten by penguins in different years, was conducted using nested ANOVA models and compared with other sampling sites in the CEMP program (Orcadas and Esperanza). The random levels defined for this analysis are: Year (Y); Day within year(D); Penguin within day (P) and Krill within penguins (K).

The Nested ANOVA model yields estimates of mean sizes and associated variance as well as a decomposition of the total variance in components associated with each random level. The analyses were also conducted on subpopulations of the penguin food such as those obtained classifying krill by sex and maturity stage; the results for three years are presented in Tables 1 and 2.

Table 1. Variance components - Results of ANOVA (P= probability, VC%= percent of total variance at a given level)

		KRILL JUVENILES		KRILL MALES		KRILL FEMALES	
Station	Level	P	VC%	P	VC%	P	VC%
JUBANY	Year	0.0004	33.36	0.5344	0.0	0.4093	0.56
	Day	0.0006	6.93	0.1298	1.85	0.0000	9.81
	Penguin	0.0020	7.69	0.0000	8.60	0.1651	2.81
ORCADAS	Year	0.6674	0	0.0018	43.01	0.9055	0
	Day	0.0777	10.42	0.4833	0	0.0039	8.71
	Penguin	0.0175	13.75	0.0037	8.78	0.0000	16.33
ESPERANZA	Year	0.0105	18.93	0.1917	0	0.0017	8.08
	Day	0.0000	25.08	0.0027	29.26	0.0019	22.42
	Penguin	0.0000	12.82	0.0000	17.87	0.0000	15.44

Table 2. Mean sizes of krill (mm). Numbers in parentheses are standard deviations

Station			JUBANY	ORCADAS	ESPERANZA
JUVENILES					
	Year	88/89	36.49 (0.41)	------	28.15 (0.89)
		89/90	32.95 (0.62)	37.61 (0.56)	34.72 (1.20)
		90/91	35.94 (0.91)	36.70 (0.46)	37.49 (1.74)
		Years pooled	35.13 (1.52)	37.08 (0.28)	33.16 (1.70)
MALES					
	Year	88/89	46.09 (0.29)	------	40.47 (0.90)
		89/90	45.05 (0.43)	45.47 (0.27)	43.32 (1.27)
		90/91	46.30 (0.46)	42.87 (0.15)	44.01 (1.78)
		Years pooled	45.84 (0.13)	44.17 (1.21)	41.79 (0.58)
FEMALES					
	Year	88/89	46.09 (0.42)	-------	38.14 (0.75)
		89/90	47.36 (0.55)	46.70 (0.52)	43.52 (1.03)
		90/91	46.11 (0.61)	47.79 (0.42)	47.25 (1.58)
		Years pooled	46.48 (0.34)	47.34 (0.27)	42.42 (1.05)

The size distribution of "penguin food" might be analyzed assuming that the variability in the feeding process is uncorrelated with krill size. This means that penguins are assumed to catch krill in a manner independent of krill size, an assumption also suggested by the absence of differences in the size eaten at the individual penguin level.

The significant component of variance between penguins in the same day implies that krill measurements obtained from a given penguin are not independent. Moreover, measurements from different penguins sampled in the same day will be also correlated. Anyway, the sample distribution of krill sizes obtained as a pool of all measurements, will converge in probability with the size distribution of penguin food. Performing exact significance tests on the differences between distributions will be impossible; but conservative tests might be designed using the numbers of penguins within days as a conservative number of degrees of freedom.

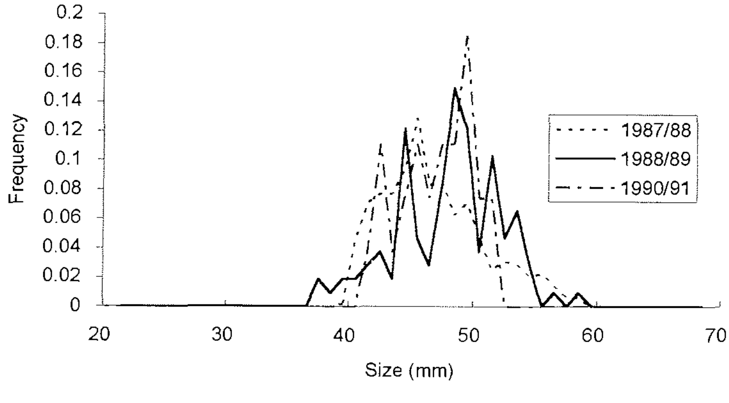
At the present stage, no information on krill density can be derived from stomach contents. It is also not yet possible to obtain from penguin stomach contents a size distribution that could be shown to converge with the size distribution of the krill population. Nevertheless, those presented in the following figures are rather similar to published size distributions of krill. Their variability can be, at least temptatively, attributed to krill variability.

Loosely speaking, the confirmation of this relation requires the empirical demonstration of the convergence between the size distribution of penguin food and the size distribution of the krill population. This can be achieved either through a detailed model of krill aggregation and penguin behaviour which seems to be unfeasible in the short or medium term or by means of simultaneous sampling of krill from the population and from stomach contents.

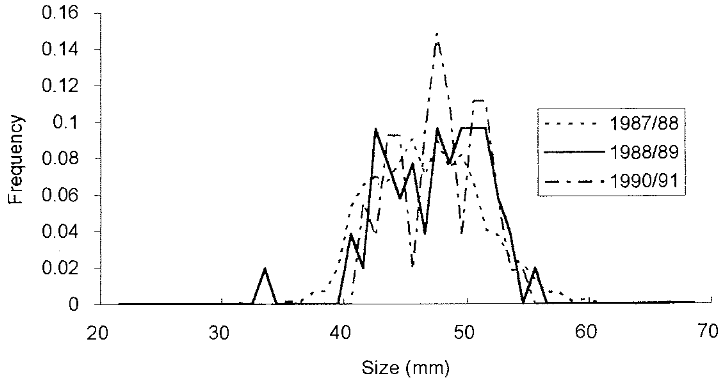
This seems to be feasible, but will require a dedicated sampling and the application of a technique with known bias, such as the use of nets together with multifrequency hydroacustics.

Figure 1. Size distribution of krill obtained from stomach contents at Potter Cove from the 1987/88 season to the 1990/91.

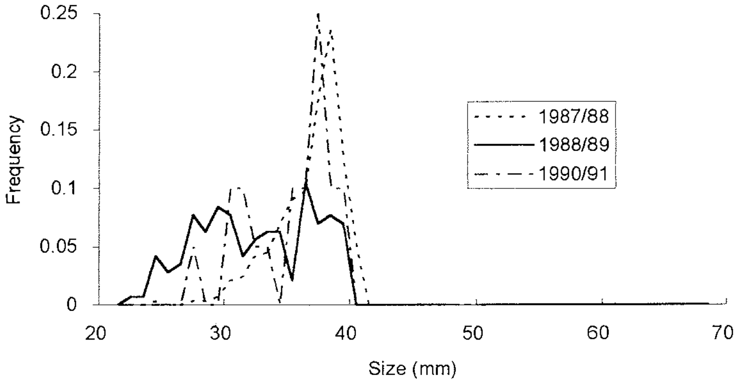
a) Females



b) Males



c) Juveniles



Reference

Marschoff, E.R. Gonzalez, B.N. (1992). Homogeneity of Adeliae penguins as krill samplers. Selected Scientific Papers SC/CCAMLR - SSP/9 1992 pp 253-257.

FISH AS PREY OF BIRDS AND MAMMALS AT THE SOUTH SHETLAND ISLANDS

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From the beginning of the Argentine scientific activities at Jubany Station in King George Island, South Shetland Islands, in 1982, several aspects of the biology of inshore demersal fish species were studied in the compass of the Ichthyology Project of the Argentine Antarctic Institute (AAI) (see Barrera-Oro and Casaux, this issue).

Considering the importance of the predator-prey interactions between birds/mammals and fish in the Antarctic ecosystem and the scarce information available on this matter from the South Shetland Islands, a research program co-ordinated by the Ichthyology, Birds and Mammals projects of the AAI was established in 1990 to understand on this matter. The initial studies were focused on the diet of the Antarctic Shag at different localities of the South Shetland Islands. Similar studies were also carried out on the South Polar Skua and on the Cape Petrel. Recently, the Weddell seal and the Antarctic fur seal were also included as target species of the program. In this review we summarise briefly the main results of this research program.

Antarctic Shag *Phalacrocorax bransfieldensis*

The studies on this shag started in 1990 and were focused on the colonies at Duthoit Point and Harmony Point, both at Nelson Island; Half-moon Island, and Bajas Rocks, close to Potter Cove, King George Island. The diet of this bird was investigated by the analysis of regurgitated casts (pellets) and stomach contents as described in Casaux and Barrera-Oro (1993a) and Coria *et al.* (1995a) respectively.

The results from both methods indicated that diet of this bird at these localities is diverse, being demersal fish largely the main prey, followed by octopods, gammarid amphipods and polychaetes (Casaux and Barrera-Oro 1993a, Coria *et al.* 1995a, Barrera-Oro and Casaux 1996, Casaux 1997). Among fish, the Antarctic cod *Notothenia coriiceps* is the most important prey, whereas *Harpagifer antarcticus* and/or *Lepidonotothen nudifrons*, depending on the studied area, followed in importance (Table 1).

We also analysed the variation in the composition of the diet throughout the breeding season. It was found that in order to respond to chicks' increasing energetic requirements, during the main rearing period the parents forage on larger fish specimens/species (such as *N. coriiceps*) than in periods of chicks' lower demands (Casaux and Barrera-Oro 1995a, Favero *et al.* 1998). At Duthoit Point we also observed an increase in the number and a decrease in the duration of the foraging trips along the breeding season, although the extension of the daily foraging activity and the mass of the loads carried to the nest did not vary significantly (Favero *et al.* 1998). On the contrary, at Harmony Point the shags also increased the extension of the daily foraging activity as well as the mass of the food loads (Casaux, unpublished data).

Table 1:Fish in the diet of the Antarctic Shag as reflected by the analysis of pellets collected at Harmony Point (A) and at Duthoit Point (B) during the 1995/96 summer season. Frequency of occurrence percent (F%), percent by number (N%) and mass (M%). Taken from Casaux (1997).

A)

	November			December			January			February		
	F% M%		N%	F%	N%	M%	F% M%		N%	F% M%		N%
N. coriiceps	80,8	34,2	87,3	83,1	22,1	74,9	71,0	9,8	59,3	79,5	10,9	65,9
H. antarcticus	3,9	33,6	5,8	28,6	54,8	13,1	53,2	72,6	28,0	53,9	76,4	27,4
L. nudifrons	7,7	7,5	2,3	15,6	8,6	5,6	35,5	7,9	7,4	25,6	5,2	5,0
T. newnesi	---	---	---	6,5	0,6	0,3	8,9	0,7	0,7	10,3	0,8	0,7
G. gibberifrons	15,4	2,7	0,2	9,1	2,0	4,0	20,2	1,1	0,3	12,8	0,8	0,1
N. rossii	3,9	2,1	2,6	2,6	0,2	2,0	1,6	0,1	1,1	---	---	---
P. charcoti	---	---	---	---	---	---	4,8	0,2	2,3	---	---	---
P. bernacchii	3,9	0,7	0,5	---	---	---	4,0	0,3	0,2	2,6	0,3	0,8
P. georgianus	---	---	---	---	---	---	0,8	0,0	0,4	---	---	---
N. coatsi	---	---	---	---	---	---	0,8	0,1	0,3	---	---	---
N. nybelini	---	---	---	2,6	0,2	0,2	---	---	---	---	---	---
E. antarctica	---	---	---	2,6	0,2	0,0	---	---	---	---	---	---
G. nicholsi	---	---	---	---	---	---	1,6	0,1	0,1	---	---	---
G. acuticeps	3,9	1,4	1,3	---	---	---	---	---	---	---	---	---
Unidentified	38,5	17,8	---	39,0	11,2	---	46,8	7,1	---	48,7	5,6	---

B)

	November			December			January			February		
	F% M%		N%	F% M%		N%	F%	N%	M%	F% M%		N%
N. coriiceps	63,6 59,6		8,3	79,3	14,7	75,2	75,9	9,2	55,3	71,7	11,7	67,0
H. antarcticus	45,5	68,6	28,1	31,0	42,6	13,4	70,7	52,4	22,1	43,4	49,6	15,3
L. nudifrons	24,2 1,3		3,3	34,5	19,4	5,5	60,3	21,2	13,4	39,6	15,8	8,2
T. newnesi	21,2 5,0		5,0	17,2	3,1	2,2	31,0	2,5	2,6	20,8	4,4	3,8
G. gibberifrons	18,2 3,2		1,3	3,5	0,6	0,0	15,5	1,3	1,3	20,8	1,9	3,1
N. rossii	3,0 2,8		0,2	6,9	0,6	3,4	3,5	0,2	2,8	---	---	---
P. charcoti	---	---	---	---	---	---	5,2	0,2	1,2	3,8	0,4	2,6
P. bernacchii	---	---	---	6,9	0,6	0,3	6,9	0,4	0,4	1,9	0,1	0,2
N. nybelini	---	---	---	---	---	---	5,2	0,4	0,2	---	---	---
Unidentified	45,5	13,4	---	58,6	18,2	---	60,3	12,2	---	49,1	16,2	---

The facts that the fish represented in the diet of this shag coincides qualitative and quantitatively with those caught by means of trammel-nets and that the analysis of pellets reflects temporal variations in the composition of the diet, make these bird susceptible to be used as indicators of changes in coastal fish populations, mostly if considered the scarce time and effort in the field required by this methodology (see Casaux and Barrera-Oro 1993b, 1995b). It was thought that previous to the implementation of a monitoring program, some problems of the method such as the species specific digestion of the otoliths found in pellets and their loss throughout the gastrointestinal tract should be solved. For such a purpose, we carried out a feeding trial (Casaux *et al.* 1995a) and we also compared stomach contents and pellets collected simultaneously throughout the breeding season (Casaux *et al.* 1995b), thus obtaining correction factors for different fish species and reproductive periods. Recently, these factors have been tested and they showed to be satisfactory (Casaux 1997). This last study also evidenced the significant role of this bird in the regulation of coastal demersal fish populations: for the 1995/96 breeding season (November to February) in colonies at Harmony Point (45 active nests) and Duthoit Point (104), shags required to rear a mean of 1.3 and 1.7 chicks per nest respectively, approximately 13 and 28.5 tons of fish, which had been caught by the birds close to the colonies. These findings are considered of potential interest for international programs aimed to monitor changes in the Antarctic ecosystem such as the *Ecology of the Antarctic Sea Ice Zone-Coastal Systems* (CS-EASIZ) and the *Commission for the Conservation of Antarctic Marine Living Resources* (CCAMLR).

In 1995 we started studies aimed to understand on the foraging strategy of this bird at Harmony Point. The aspects currently analysed are sexual differences in diving depths, organisation of the bouts and selection of foraging areas. Likewise, this information is being correlated with that on the composition of the diet as reflected by the analysis of pellets and stomach contents, breeding parameters, activity patterns and prey availability. Simultaneously, while the research process on this matter progresses, the size of the breeding populations at the colonies under study are steady decreasing.

South Polar Skua *Catharacta maccormicki*

Montalti *et al.* (1996) studied the diet of the South Polar Skua by the analysis of stomach contents collected from December 1995 to February 1996 at Half-moon Island. Fish were represented in the total of the samples and constituted the bulk of the diet (98% by mass), being followed in importance by krill. The contribution to the diet of the remaining taxa (*Pontogeneia antarctica*, *Themisto gaudichaudii*, and Mysciids) was negligible. It is likely that some of these organisms came from the fish stomachs. Eight fish species were identified: the myctophids *Electrona antarctica*, *Krefftichthys anderssoni*, *Gymnoscopelus braueri*, *Electrona carlsbergi*, *Protomyctophum normani* and *Protomyctophum tenisoni*; the nototheniid *Pleuragramma antarcticum* and the channichthyid *Chaenocephalus aceratus*. *Electrona antarctica* was the most frequent fish and also predominated by number and mass; *P. antarcticum* and *K. anderssoni* followed in importance (Table 2).

Table 2: Fish in the diet of *C. maccormicki* as reflected by the analysis of stomach contents collected from December 1995 to February 1996 at Half-moon Island. Frequency of occurrence percent (F%), percent by number (N%). Taken from Montalti *et al.* (1996).

	F%	N%	SL in mm (sd)	Mass in g %
E. antarctica	64.3	72.7	66.0 (5.2)	50.7
P. antarcticum	17.9	5.2	105.7 (52.0)	18.7
K. anderssoni	25.0	11.7	80.3 (7.9)	16.7
C. aceratus	3.6	1.3	196.0 (---)	8.2
G. braueri	3.6	1.3	84.2 (---)	1.6
P. normani	3.6	1.3	66.5 (---)	1.4
E. carlsbergi	3.6	1.3	57.1 (---)	1.4
P. tenisoni	3.6	1.3	51.3 (---)	1.2
Unidentified	10.7	3.9		

SL: Standard length, standard deviation between parenthesis

Several authors have reported fish as prey of *C. maccormicki* (Green 1986; among others) but in their studies the total contribution of fish to the diet was low. At Half-moon Island fish (mostly myctophids) were present in the total of the samples and constituted the bulk of the diet all along the breeding season. These findings, which agree with those of Reinhardt (1997) for Potter Peninsula, King George Island, indicates that at some localities and/or under certain conditions fish are much more important as prey of this bird than previously thought.

Cape Petrel *Daption capense.*

Soave *et al.* (1996) studied the diet of breeding and chick Cape petrels at Fildes Peninsula, King George Island and at Harmony Point, by the analysis of stomach contents and regurgitations collected in January-February 1996. Krill was the main prey during the whole sampling period at Fildes Peninsula, whereas at Harmony Point krill and fish were found in similar proportions in terms of mass and frequency of occurrence.

Table 3: Fish in the diet of Cape petrels as reflected by the analysis of regurgitations and stomach contents collected at Fildes Peninsula (A), and Harmony Point (B) in January and February 1996. Frequency of occurrence percent (F%), percent by number (N%) and mass (M%); mean length (± standard deviation) and size range in mm. Taken from Casaux *et al.* (unpublished)

A

Adults (n=17)	F%	N%	M%	Mean length	Size range
*E. antarctica**	83.3	64.3	49.0	52.8±9.2	41.0-70.8
*E. carlsbergi***	33.3	21.4	51.0	88.9±5.2	85.1-96.1
Unidentified	16.7	14.3	---	---	---
Chicks (n=20)					
*E. antarctica**	90.0	68.0	65.7	52.9±11.9	33.5-68.9
*G. braueri**	10.0	4.0	13.4	89.3	---
*K. anderssoni***	10.0	4.0	12.4	95.7	---
*P. bolini***	10.0	12.0	8.6	22.1±2.3	20.2-25.3
Unidentified	30.0	12.0	---	---	---

B

Adults (n=20)	F%	N%	M%	Mean length	Size range
*E. antarctica**	87.5	61.5	100.0	64.7±5.9	55.5-71.5
Unidentified	37.5	38.5	---	---	---
Chicks (n=18)					
*E. antarctica**	100.0	45.5	60.7	54.2±7.7	41.7-65.5
*K. andersoni***	50.0	9.1	39.3	96.6	---
Unidentified	50.0	45.5	---	---	---

*** Length in standard length.**

**** Length in total length.**

In the majority of the diet studies on *D. capense* where fish were represented, the Antarctic silverfish *P. antarcticum* was the unique species identified (Arnould and Whitehead 1991, among others). Although in Soave's study fish were regularly found in the samples throughout the sampling period at both localities, *P. antarcticum* was not identified. All of the fish represented were myctophids (*E. antarctica, E. carlsbergi, G. braueri, Protomyctophum bolini and K. anderssoni*), a family never reported in the diet of breeding Cape petrels (Table 3). *Electrona antarctica* was the most important prey at both sites, being followed in importance by *E. carlsbergi* at Fildes Peninsula and *K. anderssoni* at Harmony Point.

Adélie penguin *Pygoscelis adeliae*

Coria *et al.* (1995b) studied the diet of adult Adélie penguins at Stranger Point, King George Island, during the post-hatching period. The analysis of the stomach contents indicated that Euphausiids were the most frequent (100%) and important prey by mass (98.5%). Fish occurred in 83% of the samples and contributed with 1.4% of the prey mass. Among fish *P. antarcticum* was the dominant prey (62.5% by number) followed by the myctophid *E. antarctica* (26.2%) and unidentified channichthyid species.

Antarctic fur seal *Arctocephalus gazella*

Casaux *et al.* (1997a) investigated the diet of non-breeding male Antarctic fur seals at Harmony Point, by the analysis of faeces collected during February 1996 and 1997.

Overall fish were the most frequent prey and predominated by mass, whereas krill did by number. This pattern coincides with the observed in 1997 but in 1996 krill predominated also by mass. The importance of the remaining taxa was negligible.

The analysis of the samples indicated that among fish myctophids predominated in the diet being *G. nicholsi* the most important prey. This fish, followed by *E. antarctica*, predominated in 1997, whereas the channichthyid *Cryodraco antarcticus*, followed by *Gobionotothen gibberifrons*, was the main prey in 1996 (Table 4). All of the fish represented in the scats are krill-feeding species and most of them (except *Chionodraco rastrospinosus* and *C. antarcticus*) have been reported as prey of fur seals. Our results confirm the importance of myctophids in the diet of *A. gazella* at the South Shetland Islands, which was previously reported by Daneri (1996).

Table 4: Fish represented in scats of non-breeding male Antarctic fur seals collected at Harmony Point, in February 1996 and 1997. Frequency of occurrence percent (F%), percent by number (N%) and mass (M%). Taken from Casaux *et al.* (1997b).

	1996			1997			Total		
	F%	N%	M%	F%	N%	M%	F% M%		N%
Myctophidae									
G. nicholsi	16.7	22.2	18.8	45.5	43.0	82.7	35.3	40.9	70.2
E. antarctica	11.1	5.6	0.6	45.5	41.3	11.6	33.3	37.7	9.5
E. carlsbergi	5.6	53.3	14.6	6.1	3.9	2.7	5.9	8.9	5.0
K. anderssoni	---	---	---	3.0	0.4	0.2	2.0	0.3	0.2
G. braueri	---	---	---	15.2	0.6	0.4	9.8	0.6	0.3
Channichthyidae									
C. antarcticus	11.1	3.3	44.0	---	---	---	3.9	0.3	8.6
C. rastrospinosus	---	---	---	6.1	0.2	0.9	3.9	0.2	0.7
Nototheniidae									
G. gibberifrons	5.6	1.1	22.0	---	---	---	2.0	0.1	4.3
P. antarcticum	---	---	---	6.1	0.7	1.5	3.9	0.7	1.2
Unidentified	5.6	14.5	---	39.4	9.9	---	27.5	10.3	---

Several authors have reported for different areas of the Atlantic Sector of the Southern Ocean (included the South Shetland Islands) that *A. gazella* prey mainly on krill (Daneri 1996; among others) and opportunistically on pelagic fish species associated to krill swarms (see North *et al.* 1983; Daneri 1996). Although our study was carried out in an area where krill is abundant, including during the study period (see Hewitt *et al.* 1996), fish (mainly myctophids) were the most important prey, moreover in view of the higher energetic value of these fish in comparison to that of krill (Ichii *et al.* 1997). This suggests the existence of an opposite pattern to that described for those authors. Interestingly, Ichii *et al.* (1997) indicated that at Seal Island the availability of myctophids within the predators' depth range at night may have been an important factor determining that fur seals foraged on offshore and slope areas. They concluded that the availability of myctophids in addition to krill is more important for the formation of fur seals foraging areas than high krill density zones. These findings suggest that more studies are required to better understand on the relationships between fur seals and their preys, mainly in areas were myctophids are abundant.

Weddell seal *Leptonichotes weddelli*

Casaux *et al.* (1997b) studied the diet of the Weddell seal by the analysis of faeces and vomits collected at Harmony Point from January 14 to February 1 1996.

The composition of the diet was diverse and comprised both pelagic and bentho-demersal organisms. Fish were the most frequent and abundant prey, whereas molluscs (mainly the octopod *Pareledone charcoti*) predominated by mass (Table 5).

Table 5: Diet composition of *L. weddelli* at Harmony Point, Nelson Island, during January and February 1996 based on the analysis of faeces and vomits. Frequency of occurrence percent (F%), percent by number (N%) and mass (M%). Taken from Casaux *et al.* (1997a).

	Faeces			Vomits			Total		
Prey items	**F%**	**N%**	**M%**	**F% M%**		**N%**	**F% M%**		**N%**
Polychaetes (mandibles)	2.4	0.2	0.0	---	---	---	2.2	0.1	0.0
Molluscs	58.5	42.8	91.3	60.0	3.4	19.7	58.7	25.9	65.8
Octopods (beaks)	51.2	37.9	87.2	60.0	3.2	19.7	52.2	23.0	63.1
Squids (beaks)									
Psychroteutis glacialis	7.3	0.5	4.0	---	---	---	6.5	0.3	2.6
Gastropods (valves)	26.8	3.7	0.1	20.0	0.2	0.0	26.1	2.2	0.1
Bivalves (valves)	4.9	0.7	0.0	---	---	---	4.3	0.4	0.0
Crustaceans (exoskeletons)	85.4	48.0	1.5	100.0	1.3	0.1	87.0	27.9	1.0
Euphausiids									
***Euphausia* sp.**	34.1	41.3	1.2	100.0	1.3	0.1	41.3	24.1	0.8
Isopods									
Glyptonotus antarcticus	17.1	2.8	0.2	---	---	---	15.2	1.6	0.2
Amphipods									
Bovallia gigantea	17.1	3.9	0.1	---	---	---	15.2	2.2	0.0
Fish	95.1	9.2	7.2	100.0	95.3	80.2	95.7	46.2	33.2
Myctophids									
Gymnoscopelus nicholsi	17.1	1.9	1.6	100.0	75.4	76.3	26.1	33.5	28.2
Electrona antarctica	12.2	1.0	0.1	60.0	18.0	3.4	17.4	8.3	1.3
Nototheniids									
Lepidonotothen nudifrons	17.1	3.2	2.9	20.0	0.4	0.4	17.4	2.0	2.0
Gobionotothen gibberifrons	4.9	2.1	2.5	20.0	0.2	0.1	6.5	1.3	1.6
Nototheniops nybelini	2.4	0.2	0.1	---	---	---	2.2	0.1	0.1
Unidentified	7.3	0.8	---	80.0	1.3	---	15.2	1.0	---
Algae	29.3	---	---	---	---	---	29.3	---	---
Stones	26.8	---	---	40.0	---	---	26.8	---	---

Each type of sample reflected a different diet composition. Benthic preys predominated in faeces, whereas vomits were mainly composed of pelagic prey remains (mostly myctophids). This could really indicate differences in the diet of the specimens that produced both types of samples and/or that faeces and vomits reflect differentially the importance of benthic and pelagic preys.

Five fish species were identified in the samples: *G. nicholsi*, *E. antarctica*, *L. nudifrons*, *G. gibberifrons* and *Nototheniops nybelini*. The myctophid *G. nicholsi* was the most important fish prey whereas the contribution of demersal species was low. However, the importance of *G. nicholsi* was over-estimated since 96% of the specimens were obtained from the five vomits analysed.

Currently we are analysing faeces of this seal collected from October 1996 to March 1997 at Harmony Point looking for seasonal variations in the composition of the diet.

References

Barrera-Oro E. and Casaux R. 1996. Fish as diet of the blue-eyed shag *Phalacrocorax atriceps bransfieldensis* at Half-moon Island, South Shetland Islands. Cybium, 20 (1):37-45, 1996.

Casaux R. 1997. On the accuracy of the pellet analysis method to estimate the food intake in the Antarctic shag *Phalacrocorax bransfieldensis*. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-EMM-97/61, 14 pp.

Casaux R., Baroni A. and Carlini A. 1997a. The diet of the Antarctic fur seal *Arctocephalus gazella* at Harmony Point, Nelson Island, South Shetland Islands. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-CEMP-97/60, 12 pp.

Casaux R., Baroni A. and Carlini A. 1997b. The diet of the Weddell Seal *Leptonichotes weddelli* at Harmony Point, South Shetland Islands. Polar Biology, 18: 371-375.

Casaux R. and Barrera-Oro E. 1993a. The diet of the Blue-eyed Shag *Phalacrocorax atriceps bransfieldensis* feeding in the Bransfield Strait. Antarctic Science, 5 (4): 335-338.

Casaux R. and Barrera-Oro E. 1993b. Blue-eyed shags as indicators of changes in littoral fish populations. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-CEMP-93/25.

Casaux R. and Barrera-Oro E. 1995a. Variation in the diet of the Blue-eyed Shag *Phalacrocorax atriceps* throughout the breeding season at Half-moon Island, South Shetland Islands. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-EMM-95/78, 12 pp.

Casaux R. and Barrera-Oro E. 1995b. A methodological proposal to monitor changes in coastal fish populations by the analysis of pellets of the blue-eyed shag *Phalacrocorax atriceps. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group*, Document WG-EMM-95/84.

Casaux R., Barrera-Oro E., Favero M. and Silva P. 1995b. New correction factors for the quantification of fish represented in pellets of the Blue-eyes Shag *Phalacrocorax atriceps*. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-EMM-95/83, 18 pp.

Casaux R., Favero M., Barrera-Oro E. and Silva P. 1995a. Feeding trial on an Imperial Cormorant *Phalacrocorax atriceps*: preliminary results on fish intake and otolith digestion. *Marine Ornithology*, 23(2): 101-106.

Coria N., Casaux R., Favero M. and Silva P. 1995a. Analysis of the stomach content of the Blue-eyed Shag *Phalacrocorax atriceps bransfieldensis* at Nelson Island, South Shetland Islands. Polar Biology, 15:349-352.

Coria N., Fontana R., Vivequin S. and Spairani H. 1995b. Dieta del pingüino Adelia *Pygoscelis adeliae* durante el período de crianza en punta Stranger, Isla 25 de Mayo, Shetland del Sur, Antarctica. Boll Mus reg Sci nat Torino, 13(2) 377-383.

Daneri G. 1996. Fish diet of the Antarctic fur seal *Arctocephalus gazella*, in summer, at Stranger Point, King George Island, South Shetland Islands. Polar Biology, 14: 353-355.

Favero M., Casaux R., Silva P., Barrera-Oro E. and Coria N. 1998. The diet of the blue-eyed shag *Phalacrocorax atriceps* during summer at Nelson Island, Antarctica: Temporal variations and consumption rates. The Condor, 100: 112-118.

Green K. 1986. Observations on the food of the South Polar Skua, *Catharacta maccormicki* near Davis, Antarctica. Polar Biology, 6: 185-186.

Hewitt R., Demer D. and Loeb, V. 1996. Distribution, biomass and abundance of Antarctic krill in the vicinity of Elephant Island during the 1996 austral summer. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document 96/23, 10 pp.

Ichii T., Bengtson J., Hayashi T., Miura A., Takao T., Boveng P., Jansen J., Cameron M., Hiruki L., Meyer W., Naganobu M. and Kawaguchi S. 1997. Important aspects of prey distribution for the formation of foraging areas of Chinstrap penguins and Antarctic fur seals at Seal Island. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document 97/28, 24 pp.

Montalti D., Casaux R., Coria N. and Soave, G. 1996. The importance of fish in the diet of the South Polar Skua Catharacta maccormicki at the South Shetland Islands, Antarctica. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-EMM-96/32, 7 pp.

North A., Croxall J. and Doidge D. 1983 Fish prey of the Antarctic Fur Seal *Arctocephalus gazella* at South Georgia. British Antarctic Survey Bulletin, 61: 27-37.

Reid K. and Arnould J. 1996. The diet of Antarctic fur seals *Arctocephalus gazella* during the breeding season at South Georgia. Polar Biology, 16: 104-114.

Reinhardt K. 1997. Nahrung und Fütterung der Küken antarktischer Raubmöwen *Catharacta antarctica lonnbergi* und *C. maccormicki*. Journal für Ornithologie, 138: 199-213.

Soave G., Coria N., Silva P., Montalti D. and Favero M. 1996. Diet of the Cape Petrel *Daption capense* during the chick-rearing period at Fildes Peninsula and Harmony Point, South Shetland Islands, Antarctica. Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-EMM-96/17, 15 pp.

A study of shells of the Antarctic limpet *Nacella concinna* (Gastropoda, Prosobranchia) at Dallmann station, King George Island

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Introduction.

Shells of molluscs store information on life and death of their inhabitants that can be used successfully by palaeoecologists once the language of this archive is mastered. To decipher this archive up to now recent shells have been studied mainly from temperate to tropical areas (*e.g.* Schäfer 1962; Fürsich & Flessa 1991; Vermeij 1993), little attention has been paid to Antarctic shells (Cadée 1996). An opportunity to visit Dallmann/Jubany station in March 1997 gave the possibility to fill in this gap. The study concentrated on shells of the Antarctic limpet *Nacella concinna.* This is a common herbivorous macroinvertebrate in the intertidal zone down to some 20 m near Dallmann Station (Iken 1996) and the Kelp gull is here its main predator in the intertidal (Favero et al. 1997). Kelp gulls drop the shells in middens on rocks along the coast, where thousands can be easily sampled for study. Shell damage and subsequent shell repair were the main topics of my research. Besides a few shells of limpets living in the intertidal the bulk was collected from gull middens. This research is part of the Netherlands AntArctic Programme (NAAP) and was financed by the Netherlands Organization for Scientific Research (NWO). The hospitality and help at Dallmann/Jubany I highly appreciated. A longer paper will appear elsewhere (Cadée in press).

Results.

Shell damage can be divided in *pre-mortal* damage, occurring during life of the animal (this is usually repaired); *peri-mortal* damage, due to predators and leading to the death of the animal; and finally *post-mortal* damage of the empty shells after the death of the animal (Cadée 1968).

During life *Nacella* shells are infested by boring algae and considerable shell damage was due to grazing activity by *Nacella* on these boring algae of their neighbour *Nacella* shells. Overgrowth of the shells by calcareous algae *(Lithothamnion)* inhibited such grazing, but in absence of *Lithothamnion* deep hollows were scraped in the shells, with the parallel scratches by the radula of *Nacella* clearly visible. Often limpets had deposited extra calcareous layers on the inside of the shell to prevent exposure of their tissues by this grazing activity. These findings confirm observations on *Nacella* by Nolan (1991) at Signy Island.

Of the limpets consumed by Kelp gulls the larger (up to > 50 mm length) were handled in the tidal zone but most (in the range of 10 - 45 mm) were ingested entire, and the shell remains were deposited in the shell middens at their roosts in accordance with earlier observations (*e.g.* Shabica 1971; Favero et al. 1997). The shells, partly broken in the gull's gizzard, were deposited as regurgitated pellets. About 40% by weight of the material in these pellets consisted of shell fragments, the remainder of still largely intact shells. Size-frequency distribution of *Nacella* shells and shell fragments from these pellets indicated peaks in the 12-20 mm size class (large fragments and small entire shells) and in the 2-5 mm size class (fragments only). Still finer *Nacella* fragments, with a peak between 0.5 and 2 mm, were found in the faeces of Kelp gulls. In the Herring gull, feeding on bivalves in the Wadden Sea, most shells are broken in the regurgitated pellets (Cadée 1995); the univalve *Nacella* shells remain largely intact because they can be nicely packed inside each other in the pellets of Kelp gulls.

Of the entire shells collected in the gull middens, 75% showed one or more shell repairs along former shell margins (Fig. 1). Such repairs might be partly due to unsuccessful attacks by gulls, but more probably they indicate damage due to impacts of rolling stones and ice-blocks in the intertidal and shallow subtidal. A number of living *Nacella* specimens were collected stranded on the beach after storms, detached from the rocks. They also showed damage along the shell margin and even one *Nacella* was collected without any shell left! This repair frequency of 75% was high, higher than in other (smaller) intertidal gastropods at Potters Peninsula (average 8%, range 3-11%). Comparable high repair frequencies as in *N. concinna* are reported only for tropical intertidal gastropods (see Vermeij 1987), where repair is due to high unsuccessful crab predation. However, shell-crushing crabs are absent at King George Island. This indicates that palaeontologists should be careful to attribute all shell repairs in fossil shells (particularly from the tidal environment) to predators. Shell repair in *Nacella concinna* collected by Nolan (1991) at Signy Island (now in the British Antarctic Survey collections, Cambridge) was comparably high, but shell repair in the related *Nacella deaurata* collected in the sheltered harbour of Port Stanley (Falkland Islands) on my way back home April 1997, occurred only in 13% of the specimens. This corroborates my suggestion that physical damage of *Nacella* from King George Island and Signy Island is the main cause of the high (repaired) shell damage observed.

A conspicuous form of post-mortal shell damage was observed on the sandy beaches where sandblasting polished and abraded *Nacella* shells. This resulted in paper-thin shells, which finally broke apart in the top and the outer shell-ring, along the almost circular impression formed by the adductor muscle, where the shell apparently is weaker. Comparable formation of limpet shell rings ('Fazettierung'). was found by Schäfer (1962) in the surf zone of pebble beaches. The final fate of shells dropped on rocks in the gull middens will be dissolution.

Conclusion

Already during their life, shells of the limpet *Nacella concinna* are heavily attacked by boring algae, grazing *Nacella*, and impacts by stones and iceblocks in the intertidal. Damage due to grazing activity and impacts were in most cases repaired. Birds ingesting molluscs normally crush the shells, but Kelp gulls, the main predator of *N. concinna* in the intertidal, leave most *Nacella* shells intact. Gulls may leave traces on the shells when they knock them off the rocks, but these will be unrecognisable from traces of impacts by stones. Sandblasting on the beach polished and abraded *Nacella* to paper-thin shells which finally broke apart. If the *Nacella* shells do not become buried they will probably all finally dissolve, underwater as well as on land.

References

Cadée, G.C. (1968). Molluscan biocoenoses and thanatocoenoses in the Ria de Arosa, Galicia, Spain. Zoologische Verhandelingen Leiden 95: 1-121.

Cadée, G.C. (1995). Birds as producers of shell fragments in the Wadden Sea, in particular the role of the Herring gull. Géobios M.S. 18: 77-85.

Cadée, G.C. (1996). Shell preservation in Recent environments. Is Antarctica different? Circumpolar Journal 11: 75-76.

Cadée, G.C. Shell damage and shell repair in the Antarctic limpet *Nacella concinna* from King George Island. J. Sea Research (in press).

Favero, M., Silva, P., Ferreyra, G. (1997). Trophic relations between kelp gull and the Antarctic limpet at King George Island (South Shetland Islands, Antarctica) during the breeding season. Polar Biology 17: 431-436

Fürsich, F.T., Flessa, K.W. (1991). Ecology, taphonomy, and paleoecology of Recent to Pleistocene molluscan faunas of Bahia la Choya, northern Gulf of California. Zitteliana 18: 1-180.

Iken, K. (1996). Trophische Beziehungen zwischen Makroalgen und Herbivoren in der Potter Cove (King-George-Insel, Antarktis). Berichte Polarforschung 201: 1-206.

Nolan, C.P. (1991). Size, shape and shell morphology in the Antarctic limpet *Nacella concinna* at Signy Island, South Orkney Islands. J. Molluscan Studies 57: 225-238.

Schäfer, W. (1962). Aktuopaläontologie nach Studien in der Nordsee. Waldemar Kramer, Frankfurt am Main, 666 pp.

Shabica, S.V. (1971). The general ecology of the Antarctic limpet *Patinigera polaris*. Antarctic Journal US 6: 160-162.

Vermeij, G.J. (1987). Evolution and escalation. Princeton University Press, Princeton NJ, 527 pp.

Vermeij, G.J. (1993). A natural history of shells. Princeton University Press, Princeton NJ, 207 pp.

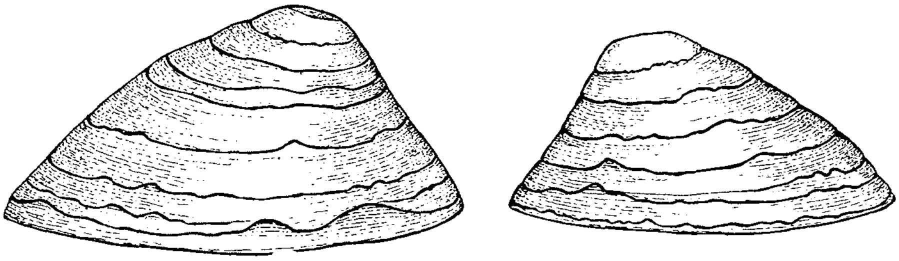

Figure 1: Shells of the limpet Nacella concinna *showing recurrent damage of the shell margin visible as ragged growth lines. These damages are supposed to be due to impacts from stones or iceblocks in the intertidal. Shell-length c. 3.5 cm.*

The Potter Cove Coastal Ecosystem - Synopsis 1998

The role of skuas in the food web of the Potter Cove system- a review

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Skuas are important top predators in different Antarctic systems (e.g. Young 1994, Emsli *et al.* 1995). There are three skua forms ocurring in the region of the Potter Cove. With respect to food web calculations, one skua form, the Chilean Skua, *Catharacta chilensis*, and their hybrids are of marginal interest, only very few birds being observed (Reinhardt *et al.* 1997). The two remaining forms, the South Polar Skua, *Catharacta maccormicki*, and the Brown Skua, *Catharacta antarctica lonnbergi*, are found in regular numbers (see Hahn *et al.*, this volume).

Habitat and diet

During the investigation period, 1993-1998, the South Polar Skua was slightly more abundant (Figure 1) in regard to both breeding pair number and number of birds in the non-breeders club. The two forms were clearly separated by their foraging habitats. The South Polar Skua mainly fed at "marine" places, as e.g. at sea or in the tidal zones. The Brown Skua preferred terrestrial sites as e.g. penguin rookeries or stony beaches (Figure 1).

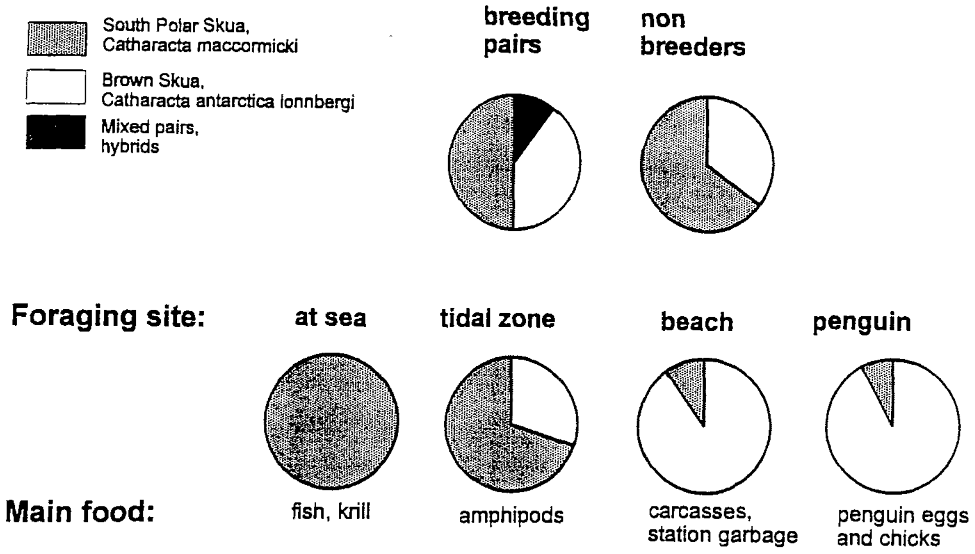

Figure 1: Frequencies (%) of three skua forms at the breeding site, the non-breders club as well as at different foraging habitats.

The clear habitat segregation of the two forms was strongly reflected in their diet, being known from several places of sympatric breeding (e.g. Trivelpiece & Volkman 1982, Pietz 1987, Peter *et al.* 1990) as well as from the Potter Peninsula itself (Reinhardt 1997). It is still a matter of dispute whether diet is the cause or the consequence of habitat segregation. Aggressive interactions observed between the two skua forms always finished with a retreat of *C. maccormicki* which, in fights with *C. a. lonnbergi* lost all out of the 49 fights recorded. Out of a further several hundred of observed aggressions, *C. maccormicki* was hardly ever able to stay at a terrestrial feeding place. In contrast, individuals observed foraging over water were always South Polar Skuas (Figure 1). In a recent review of the diet of all Southern Hemisphere skuas, Reinhardt *et al.* (In press) were able to show that in regions of allopatric breeding, fish comprises a substantial part of the diet of the South Polar Skua, although e.g. penguins were available. Penguin corpses contain a high proportion of low-energy parts, as e.g. skin and feathers and parts of the intestine which might favour the choice of fish with a higher energy input.

Carcass use by Brown Skuas

We investigated the carcass use of skuas exposing dead corpses of three penguin chicks and two adults (Adelie and Gentoo) and weighing them in discrete intervals. At the same time we recorded the number of skuas present. We furthermore observed skua behaviour at a carcass of a Southern Elephant Seal pup (Hahn & Reinhardt, unpubl. data). The total observation time was 556 skua minutes (skua minutes refer to the numbers of skuas multiplied by the number of minutes recorded. One skua minute is thus one minute with one skua, or 0.5 minutes with two skuas).

The number of skuas feeding simultaneously on a carcass differed with carcass size, with average numbers of 1.1 skuas (n = 21) on penguin carrions, and 2.5 (n = 33) on the dead seal. In all cases, a rank separation into dominant feeders and those birds that lost all fights (losers) was developed. Dominant birds defended their penguin food successfully against other birds and were present 4.5 times more often than losers. The durations of feeding spells averaged 4 min 45 sec (on seal) to 6 min 54 sec (on penguin carcass) for dominating birds and for losers from 0.5 to 1 min, respectively, (Hahn & Reinhardt, unpubl. data).

The mass decrease of penguin carcass can be described with a logistic regression model with $y = 51.6 \exp(9.36 \cdot 10^{-1}x) + 50$ (y = % carcass mass, x = feeding time in minutes; $R^2 = 0.91$, $p<0.001$, $n = 12$, Hahn & Reinhardt, unpubl. data). Thus, only 50 % of the mass of a dead penguin were used by skuas. Simultaneously, the actual food consumption, measured in consumed mass per minute, declined from 9.5 - 13.6 g/min in the beginning to only 1.0 - 1.4 g/min at the end of experimental time (Figure 2).

Food consumption

As can be seen from above, skuas contributed mainly in two ways to a nutrient cycling in the Potter Cove system: the inland transport of fish and crustaceans as performed by the South Polar Skua, as well as the decomposition of carcasses and, less important, station waste. Since numbers of breeders, non-breeders, chicks as well as their feeding habits are known, a projection of the total food consumption is possible. This figure is based (1) on the energy requirements of adult seabirds (Nagy et al. 1987), (2) energy requirements of larid chicks (Drent et al. 1992), our own unpublished data on the body

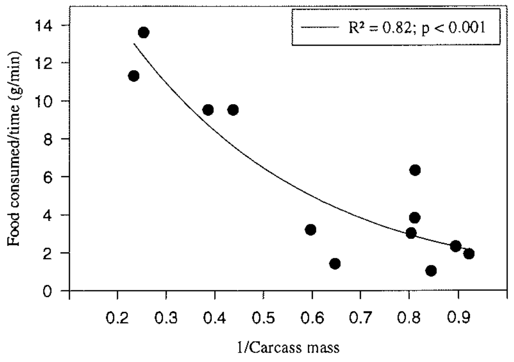

Figure 2: The food consumption of skuas depends on the exploitation rate of a penguin carcass, measured in consumed mass per time (g/min). Logistic regression curve with $y = 24 \exp(-2.6*10^3 x)$ (y = mass consumed, x = 1/carcass mass), $n = 12$.

masses of adult birds, as well as individual growth curves and average mortality ages of chicks (Reinhardt 1995). We here use the average age of mortality instead the population mortality curve.

On Potter Peninsula the food spectrum of the South Polar Skua comprised about 85 mass-% fish, about 5 mass-% krill and other crustaceans and 10 mass-% other material (Reinhardt 1997). When applying averages of metabolisable energy (krill: 3,7 kJ/g wet weight (Davis *et al.* 1989), fish: 6,3 kJ/g wet weight (Davis in Young (1994) for *Pleuragramma antarcticum)* and an average value for the remainder, an energy density of 6.13 kJ/g wet weight can be assumed (Reinhardt 1998). Adult South Polar Skuas, on average, weighed 1237 ± 175 g. Seabirds of such a mass and a diet energy density as outlined above have a daily demand of 298 g food (Nagy 1987).
Using Drent's *et al.* (1992) formula, a fledged South Polar Skua chick (average weight 1460g- Reinhardt submitted) should obtain a total of 9339 g food of the above mentioned composition during 60 days of nestling time. Non-fledged chicks died at an average age of 17 days (Reinhardt 1995). We here assume that a chick had received an average of 3100 g food by that age.

The food spectrum of the Brown Skua contains about 63 mass-% penguin meat, about 12 mass- % station garbage, 18 mass-% krill from penguin stomachs and 7 mass-% other food (Reinhardt 1997). When applying averages of metabolisable energy (krill 3,7 kJ/g wet weight (Davis *et al.* 1989), penguin chick 7,1 kJ/g wet weight (average value for a 2 kg chick- Myrcha & Kaminski 1982) and an average value for the remainder an

energy density of 6.38 kJ/g wet weight can be assumed (Reinhardt 1998). Adult Brown Skuas, on average, weighted 1,835 ± 202 g. Using Nagy's formula for seabirds of that mass, an average adult Brown skua, thus, has a daily energy demand equalling 393 g of its food.
During 60 days of nestling time and a mean fledging weight of 1765g, Brown Skua chicks should have consumed 10878 g food. Chicks that died before fledging reached an average age of 17 days (Reinhardt 1995). Here we assume that 17-days-old chicks had received 3,600g food in total.

From the above data, the breeding pair numbers (Figure 1), counts of approximately 30 skuas in the non-breeders-club and phenological data (Hahn et al., this volume), an estimation of the total food consumption of the skuas on the Potter Peninsula during the breeding season 1993/94 can be derived (Table 1).

Table 1. Skua food consumption figures for the period Dec., 1, 1993 to Feb., 28, 1994 at Potter Peninsula.

Skua	Unit	Number	Food Consumption
South Polar Skua	breeding individual	90	2414 kg
	non-breeding individual	20	536 kg
	fledged chick	21	196 kg
	chick died before fledging	23	71 kg
	Subtotal		3217 kg
Brown Skua	breeding individual	80	2830 kg
	non-breeding individual	10	354 kg
	fledged chick	27	294 kg
	chick died before fledging	17	61 kg
	Subtotal		3539 kg
Hybrid	fledged chick	5	49 kg
	chick died before fledging	8	26 kg
	Subtotal		75 kg
	TOTAL		6831 kg

When applying the food spectrum of skuas at Potter Peninsula these figures lead to total amounts of material eaten by skuas: 2734.5 kg fish, 160.9 kg krill and 321.7 kg other items (including about 161 kg amphipods) eaten by South Polar Skuas, and 2229.6 kg penguin, 637 kg krill from penguin stomachs, 424.7 kg station waste and 247.7 kg other food items eaten by Brown Skuas. Hybrid chicks received 58 kg fish, 13.5 kg penguin and 3.5 kg other material.
Assuming average penguin chick meal sizes of 250 g, the average of 637 kg krill from penguin stomachs would have required the killing or scavenging of 2548 penguin chicks. Taking further the carcass use of only 50 % into account, the intake of 2244 kg penguin by the Brown Skua and hybrid chicks would require a total mass of ca. 4500 kg "penguin". Combining smaller and larger chicks as well as adults into an average 2.5-kg- penguin, a total of ca. 1800 penguins had to be killed. It is necessary to note that the two estimates (2548 and 1795 penguins) do not include egg feeding, yet.

Assuming now that all Potter peninsula skuas feed only at the Stranger Point colony (which is not true) we can use the fledging success of penguins as a further independent control of our projection. Given an average of 18000 breeding pairs at Stranger Point (Hahn et al., this volume), a mean of 1.9 eggs per pair (Peter et al. 1988) and an average hatching success of 75 % (Peter et al. 1989), the Stranger Point colony would then produce 34200 eggs and finally 25600 chicks. With a mean success of 1.3 fledged chicks per breeding per pair with chicks (Peter et al. 1989) 23400 chicks would have fledged. The difference of 2200 chicks, and 8600 eggs is most likely attributed to skua predation or scavenging.

Our three estimates of how many penguin chicks are eaten by skuas correspond fairly well to each other. Yet, the three calculations, 1795, 2548 and 2200, respectively remain rough estimates only since many factors are not known, as e.g. the dietary differences between skua adults and chicks, exact energy densities, especially in terms of the categories fish and "meat", as well as the energetic costs of thermoregulation. Further consideration is necessary towards possible higher flight costs for the South Polar Skua and differences in the flight costs between territorial and non-territorial Brown Skuas (see e.g. Pietz 1986).

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References

Davis R W, Croxall J P, O`Connell M J (1989) The reproductive energetics of gentoo (Pygoscelis papua) and Macaroni penguin (Eudyptes chrysolophus) penguins at South Georgia, South Atlantic Ocean. J. Anim. Ecol. 58: 59-74.

Drent R H, Klaasen M, Zwaan B (1992) Predictive growth budgets in terns and gulls. Ardea 80: 5-17.

Emslie S K, Karnowsky N Trivelpiece W (1995) Avian predation at penguin colonies on King George Island, Antarctica. Wilson Bull. 107: 317-327.

Hahn S, Peter H-U, Quillfeldt P, Reinhardt K (1998) Numbers of breeding pairs and non-breeders of the birds of Potter Peninsula. Ber. Polarforsch, this volume.

Hahn S, Quillfeldt P (this volume) Ecological separation of two stormpetrel species due to predation by skuas. Ber. Polarforsch, this volume.

Hahn S, Reinhardt K (in prep.) Carcass use by skuas.

Myrcha A, Kaminski P (1982) Changes in body calorific values during nestling development of penguins of the genus Pygoscelis. Pol. Polar Res. 3: 81-88.

Nagy K A (1987) Field Metabolic Rate and Food Requirement scaling in Mammals and Birds. Ecol. Monogr. 57: 111-128.

Peter H-U, Kaiser M, Gebauer A (1988) Untersuchungen an Vögeln und Robben auf King Geoge Island, South Shetland Islands, Antarktis. Geodät. Geophysikal. Veröff.. R.I 14: 1-127.

Peter H-U, Bannasch R, Bick A, Gebauer A, Kaiser M, Mönke R, Zippel D (1989) Bestand und Reproduktion ausgewählter antarktischer Vögel und Robben im Südwestteil von King George Island, South Shetland Islands. Wiss. Z. Univ. Jena, Naturwiss. R. 38: 645-657.

Peter H-U, Kaiser M, Gebauer A (1990) Ecological and Morphological Investigations on south Polar Skuas (Catharacta maccormicki) and Braown Skuas (Catharacta skua lonnbergi) on Fildes Peninsula, King George Island, South Shetland Islands. Zool. Jahrb. Abt. Syst. Ökol. Geogr. Tiere 117: 201-218.

Pietz P C (1987) Feeding and nesting ecology of sympatric South Polar and Brown Skuas. Auk 104: 617-627.

Reinhardt (1995) Nahrungs- und brutökologische Untersuchungen an antarktischen Raubmöwen (Aves; Stercorariidae). Unpubl. M. Sc. thesis, University of Jena

Reinhardt K (1997) Nahrung und Fütterung der Küken antarktischer Raubmöwen Catharacta antarctica lonnbergi und C. maccormicki. J. Orn. 138: 199-213.

Reinhardt K (1998) Ligature use in food studies for precocial birds- pros and cons, and accuracy in Antarctic skua chicks. Ornis Fenn.

Reinhardt K, Blechschmidt K, Peter H-U, Montalti D (1997) A hitherto unknown hybridization between Chilean and South Polar Skua. Polar Biol. 17: 114-118.

Reinhardt K, Peter H-U, Wemhoff H (in press): Southern Hemisphere skuas- where do they feed on what? A review. Marine Ornithology

Trivelpiece W, Volkman N J (1982) Feeding strategies of sympatric south polar Catharacta maccormicki and brown skuas C. lönnbergi. Ibis 124: 50-54.

Young E (1994) Skua and Penguin: predator and prey. Studies in Polar Research, Cambridge University Press.

Different predational pressures on two Antarctic stormpetrel species

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Reproductive activities have been shown to increase the risk of predation in many animal species (e.g. Magnhagen 1991). Stormpetrels come to the breeding colonies only during the reproductive season. At the breeding grounds the nesting in deep crevices or burrows is one strategy to avoid predation by excavation (Warham 1996, Schramm 1983). However, on their way to and from burrows, birds may be trapped by diurnal predators. Blackbellied stormpetrel *Fregetta tropica* and Wilson's stormpetrel *Oceanites oceanicus*
are preyed upon by Skuas *Catharacta spec.* and Kelp Gulls *Larus dominicanus.* A more strictly nocturnal activity would increase the survival rate of individuals and benefit the stability of the stormpetrel population.
Skuas feed opportunistically and exploit a broad range of food reserves. Their diet is mainly determined by regional prey availibility and distribution. Differences in feeding behaviour of skuas are associated with variations in the obtainable prey species (see Reinhardt 1997). Stormpetrels have been recorded as prey of both South Polar Skua *Catharacta maccormicki*, and Brown Skua *C. antarctica lonnbergi* (see Reinhardt *et al.*, submitted, for a review). In almost all cases in which skua diets have been studied close to petrel colonies, the variability in the consumption of stormpetrels by the different skua species was high. Various authors, therefore, suggested some degree of specialisation by breeding pairs, corresponding to the local availibility of prey (e.g. Osborne 1985).
We here report observations on the nest sites, activity and flight patterns, as well as on adult morphology (Hahn 1998), that possibly show an ecological separation of both species due to differential skua predation.

Material and methods

The study was carried out in the Tres Hermanos colony at Potter Peninsula, King George Island from the end of December 1995 to March 1996 (Hahn *et al.*, this volume). The population sizes estimated by mark-recapture-experiments yielded 639-852 birds for the Blackbellied stormpetrels and 1520-2280 pairs for Wilson's stormpetrels (Hahn *et al.*, this volume). For ecological separation of these two sympatrically breeding stormpetrel species we used (1) the morphometric charcteristics of nests, (2) the predation by skuas, (3) flight activity patterns and (4) wing loading as a measurement of manoeuvrability of birds.
(1) Twenty-two nests of Blackbellied stormpetrels and sixteen nests of Wilson's stormpetrels were measured to determine width, height and length of burrow entrances.
(2) The remains of killed stormpetrels (wings and tarsi) were collected from skua pellets in the immediate vicinity of the colony. We chose three nests of South Polar Skua *Catharacta maccormicki* and Brown Skua *C. a. lonnbergi* respectively in close neighbourhood to the colony. These nests were checked every three days

and all pellets were collected and the remains of birds specified by different size and colour of the tarsi.

(3) We mistnetted birds during 24 nights in one area of the colony on the southern slope of Tres Hermanos. A 12m mist-net was used in the same position each night at the same time and numbers of caught birds were noted.

(4) Birds with a higher wing loading are not so manoeuvrable than others. The risk of falling to an avian predator increases rapidly. We measured the body mass and wing shape of 11 unsexed birds of each species. Based on their data the individual wing loading (g/cm^2) were calculated by the formula by Pennycuick (1989): wingloading = body mass/2 * wing shape + body shape between the wings.

Results

Nest characteristics

The parameters of nest entrances did not differ between the two species in regard to size (for width: t-test: $t = 0.476$, $p > 0.05$, and for height: Mann-Whitney: $T = 319.5$, $p > 0.05$, $n = 38$). However, the nests of Wilson stormpetrels had a significant shorter burrow entrance (median 30 cm) than the Blackbellied stormpetrel nests (median 40 cm; Mann-Whitney: $T = 210.0$, $p < 0.01$, $n = 38$).

Predation pressure

In skua pellets we collected remains of 67 stormpetrel individuals. The success of both skua species differed significantly: 60 (89.6%) stormpetrel remains could be found in pellets of the Brown Skua and only 7 (10.4%) in South Polar Skua pellets ($\chi^2 = 7.82$, $p<0.01$). Predation pressure did not vary between incubation and chick rearing period of the predators ($\chi^2 = 2.42$, $p>0.05$). Blackbellied stormpetrels were found 42 times, Wilson's stormpetrels only 25 times in the samples. Hence there were mean predation rates by the skuas under observation of 0.52 and 0.3 birds per day in the Blackbellied stormpetrel and the Wilson's stormpetrel, respectively, which is in contrast to the higher abundance. This combined with the information of different abundances (see Hahn et al., this volume) leads to the assumption of a 7.4 times higher risk of predation for Blackbellied stormpetrels than for Wilson's stormpetrels.

Flight activity patterns

Blackbellied stormpetrel were never observed during the day. In all months, the nocturnal activity period of Blackbellied stormpetrels was shorter than that of Wilson's stormpetrels ($\chi^2 = 22.05$, $p < 0.001$; Fig. 1). These differences subsided during the progressively longer nights. Sunset was at about 22:40 in the first, at about 21:40 in the second and at about 20:00 in last part of observation period. This indicates a higher degree of synchronisation in the nocturnal activity pattern in the Blackbellied as opposed to Wilson's stormpetrel.

Wing loading

Blackbellied stormpetrels were nearly 48% heavier than Wilson's stormpetrel (t-test: $t = 13.3$, $p < 0.001$, $n = 22$). The body mass of *Fregetta tropica* averaged 59.0 ± 3.6 g and 39.9 ± 3.2 g in *Oceanites oceanicus*. The wing areas were 109.1 ± 6.6 cm^2 as opposed to 91.5 ± 5.0 cm^2 for Blackbellied and Wilson's stormpetrel, respectively. Inspite of the larger wings of *F. tropica* the wing loadings were significantly different: 0.24 ± 0.02 g/cm^2 for Blackbellied and 0.19 ± 0.02 g/cm^2 for Wilson's stormpetrels (t-test: $t = 5.27$, $p < 0.001$). Wilson's stormpetrels flight nearly bat like, in a zig-zag course and no observed skua attacks were successfull. As opposed to this, Blackbellied stormpetrels were charcterized by a straight-line flight style and could easily be preyed upon by Brown Skuas (Quillfeldt & Hahn 1996).

Discussion

We found that Blackbellied stormpetrels were preyed upon more frequently despite their lower abundance. This is especially surprising, as *F. tropica* is exclusively nocturnal, and thus should escape predation by diurnal skuas by avoidance as well as by the dilution effect achieved by nesting sympatrically with a high number of *O. oceanicus*. An increased predation risk for breeding Blackbellied stormpetrels or their chicks could be excluded, because the measurements of nest entrances of both stormpetrel species were equal and the entrances of *O. oceanicus* were even shorter than those of *F. tropica*. Successfull predation in the crevices or burrows appears unlikely (see also Ryan and Moloney 1991). It is likely that the higher predation pressure by specialized skuas on *F. tropica* concerns flying birds and could be the reason for its more reduced and highly synchronised nocturnal activity pattern.

Our observations of skuas trying to catch either species of stormpetrel in flight indicate that the success rate is much higher for catching *F. tropica* than *O. oceanicus*. This difference is probably due to the unsteady flight style of *O. oceanicus* which contrast strongly to the straight-line flight of *F. tropica*. The flight style and the manoeuverability of the two stormpetrel species seems to be crucial for the different predation rates. If the predation rate on Wilson's stormpetrel is as low as shown in this study, why should they continue to be nocturnal? As Lima and Dill (1990) pointed out, antipredator behaviour might be so effective that predators are hardly ever successful. Thus, the lack of observed predation does not necessarily imply a lack of behavioural sensitivity to the risk of predation.

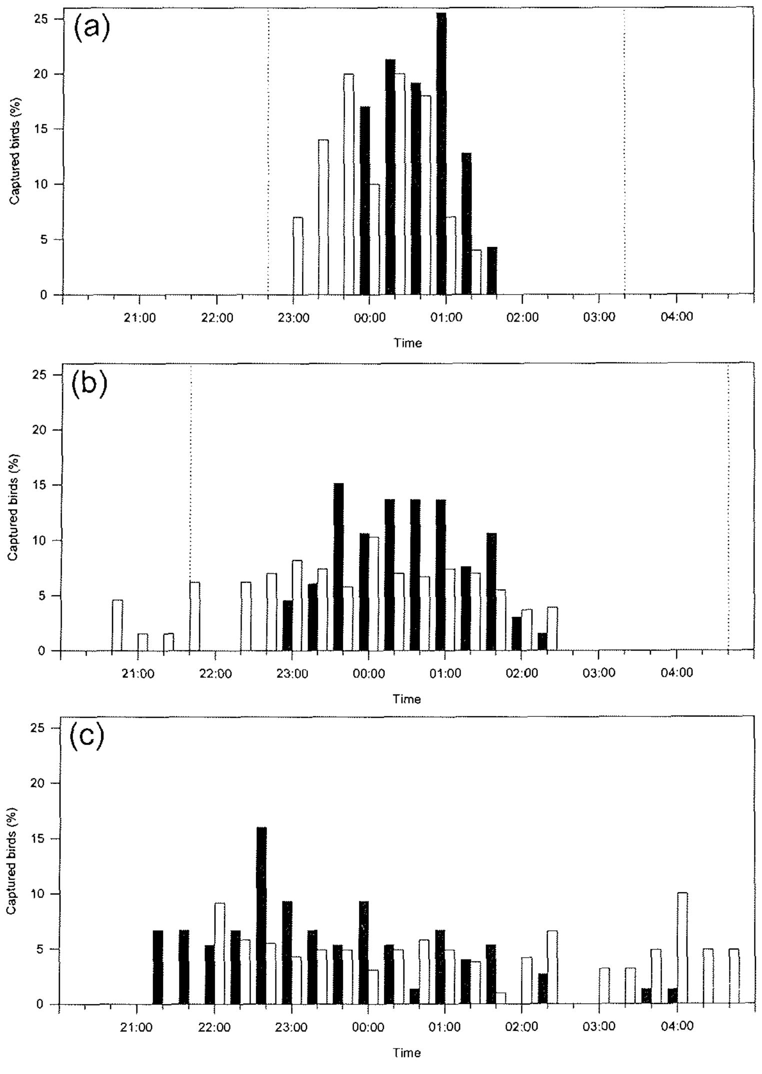

Fig. 1: Flight activity of Blackbellied (■) and Wilson's stormpetrel (□) in three periods: a) time between 19.12.95-18.01.96, b) time between 19.01.-17.02.96 and c) time between 18.02.-18.03.96. Captured birds per 20 min time intervals are stated in percent of total numbers of each species. Dotted lines in a) and b) indicate sunset and sunrise. In the last period (c) sunset and sunrise were at 20:00 pm and 06:00 am local time, respectively.

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References

Hahn S (1998) Brutphänologie und Morphometrie des Schwarzbauchmeerläufers Fregetta tropica auf King George Island, Antarktis. J Orn 139: 149-156.

Hahn S, Peter H-U, Quillfeldt P, Reinhardt K (this volume) Numbers of breeding pairs and non-breeders of the birds of Potter Peninsula.

Lima S L, Dill L M (1990) Behavioural decisions made under the risk of predation: a review and prospectus. Can. J. Zool. 68: 619-640

Magnhagen C (1991) Predation risk as a cost of reproduction. Tree 6: 183-186.

Osborne B C (1985) Aspects of the breeding biology and feeding behaviour of the Brown Skua Catharacta lonnbergi on Bird Island, South Georgia. Br. Antarct. Surv. Bull. 66: 57-71.

Pennyciuck C J (1989) Bird flight performance, a practical calculation manual. Oxford.

Quillfeldt P, Hahn S (1996) Different predation pressure, probably caused by differences in size and flight style, leads to distinct activity and populatiopn patterns in two Antarctic storm-petrels. Poster at the Meeting of the Association for the study of animal behaviour, Norwich.

Reinhardt K (1997) Nahrung und Fütterung der Küken antarktischer Raubmöwen Catharacta antarctica lonnbergi und C. maccormicki. J. Orn. 138: 199-213.

Reinhardt K, Peter H-U, Wemhoff H (submitted) Southern Hemisphere skuas - where do they feed on what? A review. Mar Ornithology - submitted 1995.

Ryan G P, Moloney C L (1990) Prey selection and temporal variation in the diet of Subantarctic Skuas at Inaccesible Island, Tristan da Cunha. Oistrich 62: 52-58.

Schramm M (1983) Predation by Subantarctic Skuas Catharacta antarctica on burrowing petrels at Marion Island. S. Afr. J. Antarct. Res. 13: 41-44.

Warham J (1996) The behaviour, population biology and physiology of the Petrels. Academic Press, London.

Kelp Gulls (*Larus dominicanus*) and Antarctic Limpets (*Nacella concinna*): Their Predator-Prey Relation at Potter Peninsula and Other Localities in the South Shetland Islands.

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From 1992 we performed ecological studies on the trophic relationships between the Kelp Gull (*Larus dominicanus*) and the Antarctic Limpet (*Nacella concinna*) at different localities on the South Shetland Islands (Silva 1996, Favero et al. 1997, Favero & Silva 1998). The relation between gulls and intertidal invertebrates remains only unmodified in Antarctica and Subantarctica (Fraser 1989, Branch 1985), as well as in other pristine places in Southamerica (Bahamondes & Castilla, 1986). However, in many areas from their wide distribution, gulls have changed their diet including anthropogenic items (Crawford et al. 1982). This was considered to be the reason of their population increases observed during the last decades (Boekel 1976 among others).

In Antarctica, Kelp gulls are important predators of the intertidal Antarctic limpets (Shabica 1976). Previous investigations on the trophic relationships between gulls and limpets in Antarctica and Sub-Antarctica have been carried out on the Antarctic Peninsula (Shabica 1971, 1976, Maxson & Bernstein 1980, Fraser 1989), South Orkney Islands (Nolan 1991) and Sub-Antarctic Islands (Blankley & Branch 1985, Branch 1985), but until 1995 no information was available from the South Shetland Islands. The aim of the current project was to increase the knowledge of this predator-prey relationship in the South Shetlands to allow the comparison with other austral localities.

Material and methods

The fieldwork was mainly carried out at Potter Peninsula (King George Island, 62°14'S, 58°38'W), Duthoit Point (Nelson Island, 62°19'S, 58°48'W) and Harmony Point (Nelson Island, 62°18'S, 59°10'W), South Shetland Islands. Samplings were performed throughout the gulls breeding season during four austral summers. Diet of gulls was determined by the analysis of 665 pellets regurgitated by kelp gulls on the breeding territories. The diet of chicks was studied by the analysis of 52 regurgitations.

Additional information on the diet was obtained from systematic observations on foraging behavior throughout focal animal observations and instantaneous scan samplings made in intertidal places at different tidal heights. Consumption rates was determined by weekly samplings of shells found in gull's nests and their respective middens. The weight of the consumed limpets was estimated by using the equations given in Favero et al. (1997).

The population abundance of limpets and their size frequency distribution was estimated on transects perpendicular to the shoreline performed during spring low tides. Each transect comprised samples from 0.25 m^2 quadrats arranged every 5 m. All limpets enclosed were collected, measured (0.01 mm) and then released. The areas sampled included protected shores at Potter Peninsula and Harmony Point (Potter and Harmony Cove, respectively), and a North shore at Harmony Point characterized by a greater exposure to waves, currents and storms.

Results

Limpets in the study area. The average size of limpets in the intertidal from Potter Peninsula was 29.4 ± 6.7 mm. This size was significantly lower than two intertidal places studied at Harmony Point, where average sizes were 37.2 ± 8.7 and 45.8 ± 7.2 mm for protected and exposed shores, respectively. The average density (individuals m^{-2}) estimated for the limpet population at Potter Peninsula (42.9 ± 66.4, n = 118) was slightly higher (Mann Whitney Z = 1.16, P = 0.248) than that observed at Harmony Point (35.6 ± 37.6, n = 132). Considering both sizes and densities, the biomass (fresh mass) of limpets in the intertidal of the latter locality was about twice (23.0 g m^{-2}) of that estimated at Potter Peninsula (12.5 g m^{-2})

Table 1. Frequency of occurrence of prey items found in 717 Kelp Gull's pellets (P) and regurgitations (R) collected from 1992 to January 1996 at different localities from the South Shetland Islands.

Item	Potter (P)[1] 92-93/93-94	Duthoit (P)[2] 94-95	Potter (P)[2] 94-95	Harmony (P)[3] 95-96	Harmony (R)[3] 95-96
Limpets	88.0	93.2	90.7	88.6	44.2
Amphipods	4.6	10.2	15.4	28.1	42.4
Isopods	0.0	1.7	0.3	0.6	1.9
Euphausiids	0.6	13.6	3.3	4.2	13.5
Cephalopods	0.0	0.0	0.0	2.4	0.0
Trochid snails	15.1	5.1	8.7	19.2	25.0
Polyplacophora	0.0	0.0	0.0	3.6	9.6
Polychaetes	0.0	0.0	0.3	0.0	3.8
Coelenterata	0.0	0.0	0.0	0.0	9.6
Fish	2.9	6.8	1.8	19.8	11.5
Scavenge	33.9	30.5	30.1	72.5	40.4
Anthropogenic	---	0.0	0.9	0.0	0.0
Sample size	107	59	332	167	52

1. Favero et al. 1997
2. Silva 1996 (unpublished Graduate Thesis)
3. Favero & Silva 1998

Diet and foraging methods of gulls. The analysis of pellets during different seasons showed that limpets were (in all localities studied) by far the most important prey of the Kelp Gulls ($F_{[occurrence]}$= 90%), followed by scavenge (42%), amphipods (15%), snails (12%), fish (8%) and euphausiids (5%). Other items present in the diet accounted for less than 3% (Table 1). Other soft bodied prey, as coelenterates and polychaetes, appeared in the diet when alternative sampling procedures were used. In chick regurgitations gammariid amphipods and euphausiids were particularly important. Among fish prey, *Electrona antarctica, Notothenia coriiceps, Gymnoscopelus nicholsii, Gobionotothen gibberifrons* and *Parachaenichtys georgianus* were the only species identified, but always of minor importance.

Gulls observed foraging on limpets in the intertidal spent half of the time searching for limpets, 10% moving between foraging areas, 10% in catching effort and 15% in handling preys. The rate of catching attempt was 3.4 ± 2.4 min.$^{-1}$. The success rate was roughly 40% (see Favero et al. 1997 for details). The average number of gulls in a rocky intertidal shore of 0.03 km^2 during spring tides was 6.3 ± 6.3 (n = 261), with a maximum of 65 individuals. Limpets were captured by three foraging methods: surface seizing and surface plunging in the case of submerged limpets (see Harper et al. 1985), and walking for exposed (not submerged) limpets (see Favero et al. 1997). This methods were used by gulls in 61, 25 and 14% of the observed attempts, respectively. Surface seizing was successful in 40% of the cases, surface plunging in 33% and walking in 50% (n.s. F = 2.50, P > 0.05).

Limpet consumption. In Potter Peninsula, the mean number of limpets eaten daily per gull during the incubation, hatching and brooding periods was 14 ± 3.3 (range 4 - 32), 20 ± 4.1 (range 8 - 30) and 17 ± 3.9 (range 4 -35) limpets, respectively (Mann Whitney U-Test $Z > 0.315$, $P > 0.100$, in all comparisons, $n = 39$). The maximum observed consumption coincided with the mid brooding period (35 limpets day^{-1} $bird^{-1}$). The size of limpets captured during the three periods differed significantly (One way ANOVA, $P < 0.001$): 25.0 ± 5.7 mm during incubation ($n = 1468$), 25.7 ± 6.0 mm during hatching ($n = 3043$) and 28.5 ± 6.7 mm during brooding ($n = 3239$).

The calculated consumption rates averaged 19.3, 30.6 and 36.7 g (wet weight) $bird^{-1}$ day^{-1} during incubation, hatching and brooding periods, respectively. Using an energetic content of 20.7 kJ g^{-1} dry weight (Blankley & Branch 1985) and a correction factor due to the occurrence of limpets handled on shore (see Favero et al. 1997 for details), consumption rates reached 102.3, 159.4 and 188.1 kJ $bird^{-1}$ day^{-1} during the three reproductive periods studied. The estimated intakes indicate that limpet resource represents between 15 and 30% (and up to 40%) of the gull's basic daily energy requirements.

Discussion

The differences found in size and morphology of limpet populations in different localities at South Shetland Islands could be attributed to their coastal characteristics. These findings are in agreement with those reported for the Antarctic Peninsula (Shabica, 1976). The observed densities were similar in limpet populations at Harmony Point and Potter Peninsula; however, the strong difference found in the average size of limpets, results in final biomass estimations about twice as high the former locality.

The database reported here shows a consistent qualitative and quantitative importance of limpets in the diet of Kelp gulls (see Favero & Silva 1998). Our results were consistent with the importance of patellid gastropods in the diet of this bird in other pristine areas in South America (Bahamondes & Castilla 1986), Sub-Antarctica (Blankley & Branch 1985, Branch 1985), South Orkney and Antarctic Peninsula (Fraser 1989, Nolan 1991, Brêthes et al. 1994). Contrasting with the literature from Antarctic Peninsula (Fraser 1989, Maxson & Bernstein 1984), the importance of fish as prey was always negligible in all monitored seasons.

Limpets were also substantial in the diet of chicks represented by the regurgitations obtained (Favero & Silva 1998); however, other items acquire significance in the diet as amphipods, snails and krill. These differences could be attributed to sampling procedures (see Duffy & Jackson 1986) or to the origin of the samples since chicks could be reared with a special diet different than that of adults. Chicks' diet was very different in comparison with that of the Antarctic Peninsula (Fraser 1989), where nestlings were almost exclusively fed with the pelagic fish *P. antarcticum*. In South Shetland Islands, the presence of fish in the diet of gulls could be attributed to offshore or intertidal predation, but also to kleptoparasitism or scavenging in association with other bird and seal colonies. The few otoliths found in the samples belonging to Nototheniid and Myctophid species; however, no *P. antarcticum* was observed. These differences could be due to a greater abundance of this fish close to the peninsula (Slosarczyk & Cielniaszek 1985, Kellerman 1986), combined with the wide intertidal shores observed in South Shetlands that could be highly attractive as alternative foraging areas, because of their proximity to the breeding places and their high predictability.

Since gulls cannot reach prey in the water column at depths greater than one body length, the number of gulls foraging on limpets and their behaviour was highly dependent on the tides. These facts were consistent with previous works on gulls (Shabica 1976, Branch 1985, Fraser 1989, Nolan 1991). Other weather conditions as winds could influence the concentration and availability of other items. For example, as result of strong winds and storms, krill could be abundant nearshore, and then easily scavenged by kelp gulls among other bird species (Favero 1996).

It has been suggested that during their breeding seasons Arctic and Antarctic Larids exploit a greater proportion of oceanic items while intertidal prey is mainly captured during the rest of the year (Annett 1987). The reduced importance of pelagic prey in the chicks' diet and the high numbers of fledglings per pair observed in some places at South Shetlands (see Favero & Silva 1998), shows indeed that these prey items are not an essential factor for breeding success. Despite the oceanic food sources are highly abundant during the summer season, their availability is more variable than those from intertidal environments. Therefore the possession of feeding territories as intertidal areas could offer several benefits as time-energy saving, predation-reducing advantages, and a more predictable food supply than oceanic resources.

Preliminary estimations of limpet consumption by gulls at Potter Peninsula gave rates between 3400 and 4800 limpets d^{-1}, and 3.1 to 4.3 limpets m^{-2} y^{-1} (see Favero et al. 1997). If an average density of 30 limpets m^{-2} is assumed (Silva 1993 and this work), predation by gulls accounts for 10-14% of their total annual mortality. The predation rate observed not only accounts for important mortality of limpets in the intertidal but also could affect the population structure of limpets through the selection of particular prey sizes, fact that was observed in our last studies (Silva et al. unpublished).

The fact that limpets represent between 15 and 30% (and up to 40%) of daily energy requirements of Kelp gulls, agrees with the historical and biogeographical evidence on the relationships between limpets and gulls. Fraser (1989) cites the coincidence in the southern limits of the distribution of both species, noting that without limpets, kelp gulls would be probably unsuccessful in Antarctica and most of Subantarctica. Also, the distribution patterns of presence and absence of both species in Antarctic and Subantarctic areas denote clearly that the presence of limpets in the intertidal represents an important attribute for the selection of breeding places. The greater abundance of gulls at Harmony Point (120 pairs, Silva et al. unpublished) compared to Potter Peninsula (49 pairs, Favero et al. 1997) is consistent with our estimations of limpet biomass, about double in the former locality.

Further studies on the foraging strategies of Kelp gulls predating upon Antarctic limpets in diverse habitats from South Shetland Islands and Antarctic Peninsula will be developed, with the aim of reach a better knowledgement and understanding of the variables involved in the energy balance of this predator-prey relationship and the related consequences in the life-histories of both species.

References

Annett C (1987) Proximate mechanisms affecting dietary switches in breeding gulls. Studies in Avian Biology 10: 102.

Bahamondes I and Castilla JC (1986) Predation of marine invertebrates by the Kelp Gull *Larus dominicanus* in an undisturbed intertidal rocky shore of central Chile. Rev Chilena Hist Nat 59:65-72.

Blankley WO and Branch GM (1985) Ecology of the Limpet *Nacella delesserti* (Philippi) at Marion Island in the Sub-Antarctic southern ocean. J Exp Mar Biol Ecol 92:259-281.

Boekel C (1976) Extension of range in the Dominican Gull. Aust Bird Watcher 6:162-167.

Branch GM (1985) The impact of predation by Kelp Gulls *Larus dominicanus* on the Subantarctic limpet *Nacella delesserti*. Polar Biol 4:171-177.

Brêthes JC, Ferreyra G and De La Vega S (1994) Distribution, growth and reproduction of the limpet *Nacella* (*Patinigera*) *concinna* (Strebel 1908) in relation to potential food availability, in Esperanza Bay (Antarctic Peninsula). Polar Biol 14:00-00.

Crawford RJM, Cooper J and Shuldon PA (1982) Distribution, population size, breeding and conservation of the Kelp Gull in Southern Africa. Ostrich 53:164-177.

Duffy DC and Jackson S (1986) Diet studies of seabirds: a review of methods. Colonial waterbirds 9: 1-17.

Favero M (1996) Antarctic Tern *Sterna vittata* feeding on the stranded krill at King George Islands, South Shetland Island, Antarctica. Marine Ornithology 23: in press.

Favero M, Silva MP and Ferreyra G. 1997. Trophic relationships between the Kelp Gull and the Antarctic Limpet at King George Island, South Shetland Islands, Antarctica. Polar Biology 17: 431-436.

Favero M and Silva MP (1998) How important are pelagic preys for the Kelp Gull during chick-rearing at the South Shetland Islands?. Polar Biology 19: 32-36.

Fraser WR (1989) Aspects of the ecology of Kelp Gull (*Larus dominicanus*) on Anvers Island, Antarctic Peninsula. Ph.D. Thesis, Univ. Minn., Minn. USA.

Kellermann A (1986) Geographical distribution and abundance of postlarval and juvenile *Pleuragramma antarcticum* (Pisces, Notothenioidei) off the Antarctic Peninsula. Polar Biology 6: 111-119.

Maxson SJ and Bernstein NP (1980) Ecological studies of southern black-backed gulls, blue-eyed shags and Adelie penguins at Palmer Station. Antarct J U S 15:157.

Nolan CP (1991) Size, shape and shell morphology in the Antarctic Limpet *Nacella concinna* at Signy Island, South Orkney Islands. Jour Moll Stud 57:225-238.

Shabica SV (1971) The general ecology of the Antarctic Limpet *Patinigera polaris*. Antarct J U S 60:160-162.

Shabica SV (1976) The natural history of the Antarctic limpet *Patinigera polaris* (Hombron and Jaquinot). Ph.D. Thesis. Univ. Oregon. USA.

Silva MP (1993) Ecologia de *Nacella concinna* (Strebel, 1908) en Península Potter, Islas Shetland del Sur. In "Reporte de datos acerca de la estructura y dinámica de un ecosistema costero antártico". Cont Inst Ant Arg 419:33-35.

Silva MP (1996) The diet of the Kelp Gull *Larus dominicanus* at South Shetland Islands, Antarctica (in spanish). Graduate Thesis. Univ. Nacional Mar del Plata, 55 pp.

Slosarczyk W and Cielniaszek Z (1985) Postlarval and juvenile fish (Pisces, Perciformes and Myctophiformes) in the Antarctic Peninsula during BIOMASS- SIBEX, 1983/1984. Polish Polar Research 6: 159-165.

5. HUMAN IMPACT AND EFFECT OF INCREASING UV-RADIATION ON THE ECOSYSTEM

TRACE METALS IN SOME INVERTEBRATES, FISHES AND BIRDS FROM POTTER COVE

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Antarctica has been usually included among the few remaining pristine regions of the planet and environmental contamination research on Antarctic ecosystems become of great interest for the international scientific community during the last years. The Antarctic marine environment provides unique opportunities for science to understand the effects of human perturbations on the natural environment.

The relatively pristine environment has been mostly associated with its isolation from the large industrial centres, far from any human activity. However, in addition to isolated incidents such shipwrecks (i.e. Bahía Paraíso at the Anvers Island in 1989), a continuos but low level of contamination does exist due to scientific facilities and their associated activities. Human settlements (both abandoned and active stations) have been indicated as the principal focus of chronic contamination. Recent studies have demonstrated the occurrence of a more contaminated halo around scientific stations, specially by detecting hydrocarbons and trace of metals. In most cases, pollutants are concentrated and circumscribed within an area of a few hundred meters radius from stations, rapidly decreasing with distance from the emission focus (Kennicutt, 1995). Although in almost every case, concentration of contaminants has been very low and below the accepted toxicity levels, it is imperative an environmental monitoring in order that a harmonious and viable ecosystem can be developed and maintained.

In the last few decades, the importance of the detection and quantification of trace elements in natural matrices (waters, sediments, biota) has increased noticeably as a consequence of a number of factors that are an unequivocal sign of anthropogenic activity. The use of organisms is one of the most widely employed method to monitor trace elements in marine coastal environment (Phillips, 1990). Marine organisms take up and accumulate trace metals in soft tissues to concentrations several orders of magnitude above the environmental levels. Organisms employed to quantify trace metals bioavailability or abundance by virtue of their tissue contend have been referred to as bio-monitors or bioindicators. Analysis of organisms offer some advantages over the analysis of the abiotic compartments: they only accumulate the biologically available forms of the pollutant, and always present in the environment, thus they can be used for the continuous pollutant monitoring. Since fluctuations in the pollutant concentration are time-integrated, magnification afforded by bioaccumulation may be advantageous regarding to the accuracy and expense of analysis of trace pollutants near the limits of analytical detection.

Most of the papers published on the suitability of organisms as pollution bioindicators focused on invertebrates, mainly molluscs, and crustaceans. Furthermore, the use of fish as biological indicators for marine pollution monitoring is widely recognised at present (Phillips, 1977). Birds have also been successfully used to monitor heavy metals pollution due to their wide distribution and their role in the food chain. (Appelquist, 1985)

Keeping in mind the above mentioned concepts, an Environmental Monitoring Programme (EMP) was designed to evaluate the occurrence, concentration and distribution of several trace metals in the Potter Cove ecosystem.

The EMP at Potter Cove has four major objectives:

- To establish the baseline of trace elements in the Potter Cove marine ecosystem
- To identify bio-monitors
- To assess bioaccumulation and biomagnification processes
- To assess the bio-geochemical cycles of the considered elements

Since 1992, the EMP has been carried out by researchers from the Argentine Antarctic Institute (IAA, Buenos Aires) and other institutions (Argentine Institute of Oceanography -IADO- (Bahía Blanca), LAQUIGE-CONICET (Buenos Aires), Naval Hidrographic Service - SHN (Buenos Aires) and the National Atomic Energy Commission - CNEA(Buenos Aires).

The present study describes the preliminary results obtained in several biological matrices, including invertebrates and vertebrates.

MATERIALS AND METHODS

Potter Cove is a particularly well-known Antarctic environment located at King George Island, in the Southern Shetland Islands, which has been widely described in previous chapters. The samples analysed were collected during the 1992/93, 93/94, 94/95 and 95/96 austral summer seasons, in the surrounding of Jubany Station

Sampling: Careful sampling and storage procedures were followed in order to assure the validity of the results obtained. The obtainment of biotic samples was assigned to the corresponding specialists on each subject (i.e. sampling and conditioning of molluscs were assigned to specialists in molluscs physiology). In the case of superior animals, it was decided to use tissues of specimens sacrificed for other research purposes (it was decided not to sacrifice superior animals, at least during the pilot stage of the programme). In all cases, the programme has focused to perform the monitoring of heavy metals by making the best use of available logistic and human resources and causing the minimum disturbance to the native flora and fauna. Samples collected during the mentioned austral summers included :

Invertebrates: samples of *Laternula elliptica* and *Odontaster validus* were manually collected by scuba divers, while those of *Nacella concinna* were obtained in the intertidal area during low tide. Samples were adequately kept in plastic bags, and conveniently stored at -20°C until their treatment at the laboratory.

Vertebrates:

Fishes: twenty five specimens of both sexes of *Notothenia coriiceps* were collected at Potter Cove during January and February 1995 and 1996. After collection the specimens were measured in total length (in cm), weighed (in g) and dissected to obtain the different tissues and sexes. All samples were immediately frozen to -20°C until analysis in Buenos Aires.

Birds: During the four mentioned summer periods samples of several tissues of *Pygoscelis adeliae, Pygoscelis papua, Chionis alba* and *Phalacrocorax atriceps* were obtained. Only recently dead animals, without evidence of damage or deterioration signal, were taken. Specimens were immediately frozen at -20ºC until autopsy and analysis.

Trace elements determination: For the analytical determination of heavy metals (Pb, Zn, Cu, Fe, Mn and Cd) in biological matrixes the methodology previously reported by Marcovecchio *et al.* (1988) was followed, which included an acid mineralization (with a nitric - perchloric acids mix) under controlled temperature. After this, atomic absorption spectroscopy (AAS), with air/acetylene flame, and deuterium background correction (D_2BGC) was applied. Both, a Shimadzu AA-640-13 and a Perkin-Elmer 2380 atomic absorption spectrophotometers were utilised to perform trace metals measurements in invertebrates and birds (*Pygoscelis adeliae, Pygoscelis papua, Chionis alba* and *Phalacrocorax atriceps*). Inductively coupled plasma atomic emission spectrometry technique (ICP-AES) was utilised to determine trace metals in fish (*Notothenia coriiceps*).

Total mercury was determined using the cold vapour atomic absorption spectrophotometry methodology (CV-AAS). Samples were pre-digested in a sulphuric-nitric acid mixture at 60 °C. The digestion was completed with 6 % potassium permanganate solution. The excess of permanganate was eliminated using 20 % hydroxylamine hydrochloride solution, and to reduce Hg(II) to Hg^0, a Sn(II) chloride solution was used. Determinations were made with a Buck Scientific 200 A atomic absorption spectrometer.

Analytical grade reagents were used to build up the corresponding blanks and calibration curves. Certificate reference materials (mussel flour standard tissue), provided by The National Institute for Environmental Studies (NIES) from Tsukuba (Japan) were used for the validation of the studies performed. Recovery obtained in the analysis of these reference materials are shown in Table 1

Table 1: Recovery of the analysis of reference materials to assess analytical accurance.

METAL ANALYSED	RECOVERY (%)
Cd	91 - 99
Zn	96 - 102
Cu	93 - 99
Mn	91 - 98
Fe	96 - 102
Hg	90 - 98

RESULTS AND DISCUSSION

Trace metals in Antarctic invertebrates:

Table 2 shows total mercury, cadmium, zinc and copper contents in the molluscs, *Laternula elliptica* and *Nacella concinna* and the starfish *Odontaster validus*.

Table 2: Total mercury, cadmium, zinc and copper contents in *Laternula elliptica*, *Nacella concinna* and *Odontaster validus.*
n: number of samples analysed, (*) pooled sample (10 specimens/sample).
Concentration: mean value ± standard deviation / range, µg g^{-1} wet wt.

Species	n	Tissue	Cd	Zn	Cu	Hg
Laternula elliptica	20	Whole	0.7±0.4 0.2-1.2	14.1±3.0 10.8-17.9	3.9±1.6 1.9-5.8	< 0.04
Nacella concinna	20 (*)	Whole	3.4±1.5 1.9-5.0	11.2±1.5 9.7-14.2	11.0±2.2 8.6-13.9	< 0.04
Odontaster validus.	8	Arm	8.2±3.1 5.0-12.2	22.9±3.2 19.4-27.5	10.6±2.4 7.2-13.5	< 0.04

In all samples analysed the levels of total mercury were below the detection limit of the method (0.04 µg/g w.w). In contrast, cadmium was detectable in all the species analysed and *Odontaster validus* showed highest cadmium levels.
Other metals studied (copper and zinc) have presented similar distribution trends in assessed species even though their concentrations were significantly different. Lower levels of trace metals (Hg, Cd, Zn) were found in *L elliptica* than in bivalves from East Antarctica. In contrast, Cu levels detected in bivalves from Potter Cove were higher than those observed in bivalves from East Antarctica. (Honda et. al., 1987, 1990, Berkman et. al., 1992).
The contents of metals in bivalves usually depend on biological factors as body size (related to age) and sex (Boyden, 1974). No correlation between metal contents and shell length was observed neither in *L. elliptica* nor in *N. concinna*. Similar results were reported by Honda et. al., 1987 for *Adamussium. colbecki* from Syowa Station.
Trace metals concentrations in *N. concinna* have been significantly lower in our studies than those reported for limpets collected in contaminated coastal environment. (Bryan, et. al., 1977) but higher than those found in samples collected in the Antarctic Peninsula. (Moreno et. al., 1997,). The relatively high level of cadmium found in *N. Concinna* may be due to its longevity (Picken, 1980) or to the presence of metallothioneins involved in the mechanism of Cd detoxification in the muscle tissue (Nöel-Lambot et. al., 1980).
The cadmium levels in *Odontaster validus* from Potter Cove were similar to those previously reported by Moreno (1997) for the same species from Ardley Island. This species preys on the widest range of food items known for Antarctic asteroid (Arnaud, 1977). Furthermore, the low pressure of predation on certain species, like *O. validus*, determined that it may live more than 100 years. The strong Cd accumulations in this species may be due to its longevity, rather than to a availability of Cd in the diet. This could also be related with the presence of metallothionein in the tissue, as reported for other asteroids (den Besten, 1989).

Trace metals in Antarctic vertebrates
Table 3 shows the metals contends in liver, muscle, gonads and kidney of the Antarctic cod *Notothenia coriiceps.*

Table 3: Metals contends in liver, muscle, gonads and kidney of Antarctic Cod *Notothenia coriiceps*. (*) Cadmium: n=5

Tissues	n	Cd	Zn	Cu	Hg
Liver	25	0.12 ± 0.05 (*)	26.4 ± 6.1	2.0 ± 0.7	0.05 ±0.03
kidney	25	0.16 ± 0.05 (*)	23.5 ± 8.7	1.6 ± 0.5	< 0.01
gonads	25	< 0.05 (*)	25.2 ± 4.9	1.7 ± 0.5	< 0.01
muscle	25	< 0.05 (*)	4.8 ± 1.0	1.01 ± 0.4	0.02 ± 0.01

The mean total length and mass (± sd) of the specimens was 35.2 ± 3.1 cm and 675.1 ± 126.2 g. Increase of metals levels with body length or weight were not observed as previously reported by Moreno et. al. (1997).

The relative metal levels of all of the analysed tissues was as follow: Fe>Zn>Cu-Mn>Cd-Hg.

In general, the metal levels in liver, kidney and gonad were higher than those measured in the muscle tissue. The metal levels in muscle nearly agree with those reported by Honda et. al. (1983) for the pelagic Antarctic fish *Pagothenia borchgrevinki*. Both fishes have in common the krill (*Euphausia superba*) as the most important food item in late spring and summer. Despite that *N. coriiceps* is an euriphagous feeder and seasonally changes its diet according to prey availability, krill is the main component in its diet when present. (Casaux et. al. 1990).

Figures 1, 2, 3 and 4 show total mercury, cadmium, zinc and copper contents in muscle and liver of *Pygoscelis adeliae, Pygoscelis papua, Chionis alba* and, *Phalacrocorax atriceps.*

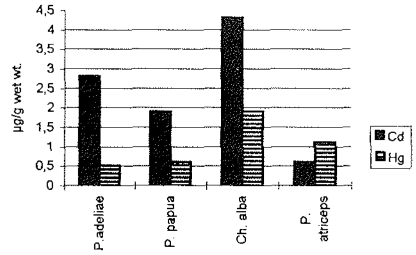

Figure 1: Cadmium and total mercury in muscle of Antarctic seabird

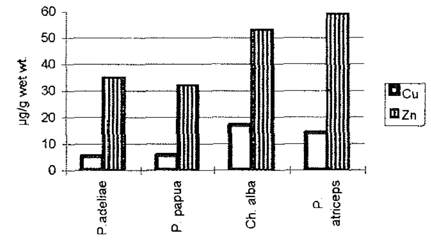

Figure 2: Copper and zinc contents in muscle of Antarctic seabird

In the majority of the bird analysed, copper and zinc levels were highest than those of mercury and cadmium. Moreover, trace metals levels (essential and non-essential) were highest in liver than in muscle. *Chionis alba* and *Phalacrocorax atriceps* showed higher levels of mercury and copper in muscle and mercury, zinc and copper in liver than those found in penguins. In contrast *Pygoscelis adeliae* presented the highest cadmium and zinc levels in muscle. Available evidence indicates than differences in metals contents between species may presumably reflect differences in feeding habits more than metabolic differences (GESAMP, 1988). The main components of diet of *Phalacrocorax atriceps* are fishes, followed by polychaetes, gastropods and bivalves, whereas *Chionis alba* eats human garbage, algae, eggs, penguin chicks and bird and mammal excreta. The low mercury levels found may be explained by the fact that krill which is the main food item of the Adélie penguin (Lishman, 1985), contains a relatively low concentration of Hg (0.008 ± 0.003 µg Hg/g wet weight; Yamamoto, 1987).

Moreover, shags and sheatbills reach the South American coast and they must feed in both relatively pristine and non-pristine areas, while penguins *pygoscelis adeliae* and *Pygoscelis papua* have an Antarctic subantarctic.

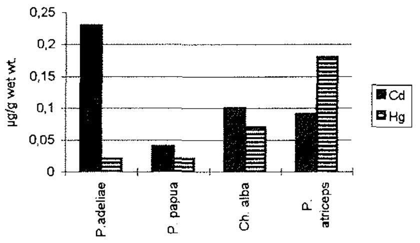

Figure 3: Cadmium and total mercury in liver of Antarctic seabird

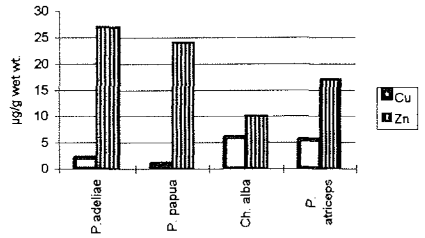

Figure 4: Copper and zinc contents in liver of Antarctic seabird

Figure 5 shows the total mercury contents in organs and tissues of adult specimens of *Pygoscelis adeliae*.

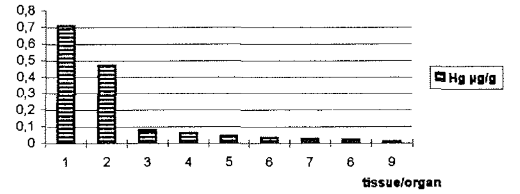

Figure 5: Total mercury content in tissues and organ of P. adeliae. 1 feather (tail)*, 2: feather (wing)*, 3: liver, 4: kidney, 5: heart, 6: fat, 7: muscle, 8: egg (yolk) and 9: egg (albumen). *[µg/g dry weight]

The observed trend of total mercury levels was similar to that reported by several authors for Antarctic and subantarctic penguins (Honda, 1987; Norheim, 1987; Muirhead, 1988), with concentrations in feathers > liver > kidney > heart > fat > muscle > egg. In general, mean total mercury contents in

Adélie penguins from the Potter Cove were generally higher that those reported for East Antarctic specimens (Honda, 1987).

5. CONCLUDING COMMENTS

The occurrence of heavy metals in some marine organisms from Potter Cove has been verified, and some data the content of trace metals in vertebrates (fishes and birds) and invertebrates are available.

Although, the utilisation of biological indicators is an excellent tool for environmental diagnosis and evaluation, the use of the studied organisms as bio-monitors or bioindicators should still be assessed. This study may allow the selection and recommendation of candidate species for continued monitoring in the area.

Cadmium, zinc and cooper showed metal-specific bioaccumulation, but not biomagnification was observed. However, a low level of biomagnification of mercury in the analysed organisms was found when we compared the total mercury content of invertebrates and vertebrates muscle tissues.

The preliminary results obtained during the first step of the EMP at Potter Cove provide evidence that this research line could be a good tool to assess the presence and bioavailability of metals in this ecosystem.

6. REFERENCES

Appelquist, H.; Drabaek I. and Asbirk, S. (1985). Variation in Mercury Content of Guillemot Feathers over 150 Years. Mar. Pollut. Bull. 16: 244-248.

Arnaud, P.M. (1977). Adaptations within the Antarctic marine benthic ecosystem. In Adaptations within Antarctic ecosystems: Proceedings of the third SCAR Symposium on Antarctic biology Gulf (Llano, G.A. ed). Houston: 135-157

Berckman, P. & Niro, M. (1992). Trace metal concentrations in the scallops around Antarctica: extending the Mussel Watch Program to the Southern Ocean. Mar. Pollut. Bull. 24 (6): 322-323.

Besten P.J. den, Herwig H.J., Voogt, P.A., Zandee D.I. (1989). The presence of metallothionein in the sea star *Asterias rubens*. In Heavy metals in the environment vol 1 (J P Vernet ed). CEP Consultants Ltd, Edinburgh, UK, 582-585

Boyden, C. R. (1974). Trace element content and body size in molluscs. Nature, 251: 311-314.

Bryan, G.; Potts, G. and Forster, G. (1977). Heavy metals in the gastropod mollusc *Hiliotis tuberculata* (L). J. Mar. Biol. Assoc., 57: 379

Casaux R., Mazzotta A., Barrera-oro, E. (1990). Seasonal aspects of the biology and diet nearshore nototheniid fish at Potter Cove, South Setland Islands, Antarctica. Polar Biology 11: 63-72.

GESAMP (1988). Arsenic, Mercury and Selenium in the Marine Environment. UNEP Regional Reports and Studies Nº 92.

Honda, K., Sahrul, M., Hidaka, H. Tatsukawa, R. (1983). Organ and tissue distribution of heavy metals, and their growth-related changes in Antarctic fish *Pagothenia borchgrevinki*. Agric. Biol. Chem 47: 2521-2532.

Honda, K.; Yamamoto, Y. & Tatsukawa, R. (1987). Distribution of heavy metals in Antarctic marine ecosystem. Proc. NIPR Symp. Polar Biol., 1: 184-197.

Honda, K., Yamamoto, Y., Hidaka, H. & Tatsukawa, R. (1986). Heavy metal accumulations in Adélie penguin, *Pygoscelis adeliae*, and their variations with the reproductive process. Mem. Natl. Inst. Polar Res., Spec. Issue, 40: 443-453

Kennicutt II, M., Mc Donald, S., Sericano,J., Boothe, P., Oliver, J., Safe, S., Presley, B., Liu, H., Wolfe, D., Wade, T., Crockett, A. and Bockus, D. (1995). Human contamination of the Marine Environment - Arthur Harbour and Mc Murdo Sound, Antarctica. Environ. Sci. Technol., 29: 1279-1287.

Lishman, G. S. (1985). The food and feeding ecology of Adélie penguins (*Pygoscelis adeliae*) and Chinstrap penguins (*P. Antarctica*) at Signy island, South Orkeney Islands. J. Zool., Lond. (A) 205: 245-263.

Marcovecchio J., Moreno, V. & Pérez, A. (1988). Determination of heavy metal concentrations in the biota of Bahía Blanca, Argentina. Sci.Tot.Environ., 75: 181-190.

Moreno de, J., Gerpe, M., Moreno, V. and Vodopivez, C. (1997). Heavy metals in Antarctic organisms. Polar Biol. 17: 131-140

Muirhead, S. J. & Furness, R. W. (1988). Heavy metals concentrations in the tissues of seabirds from Gough Island, South Atlantic Ocean. Mar. Pollut. Bull. 19: 278-283.

Nickless, G., Stenner, R., and Terrile, N. (1972). Distribution of cadmium, lead and zinc in the Bristol Channel, Mar. Poll. Bull., 3: 188

Nöel-Lambot, F., Bouquegneau, J., Frankenne, F. & Distéche, A. (1980). Cadmium, zinc and copper accumulation in limpets (*Patella vulgata*) caught off the Bristol Channel with special reference to metallothionein. Mar.Ecol.Progr.Ser., 2: 81-89.

Norheim, G. (1987). Level and interactions of heavy metals in seabird from Svalbard and the Antarctica. Environ. Pollut., 47: 83

Phillips, D.J.H. (1977). The use of biological indicator organisms to monitor trace metals pollution in marine and estuarine environments - a review. *Environ. Pollut.*, 13: 282-317

Phillips, D. (1990). Use of macroalgae and invertebrates as monitors of metal levels in estuaries and coastal waters. In: Heavy metals in the Marine Environment. (Furness, R. and P. Rainbow, eds), CRC Press, Inc. Florida, U.S.:81-99

Picken, G. B. (1980). The distribution, growth and reproduction of the Antarctic limpet *Nacella (Patinigera) concinna* (Strebel, 1908). J. Exp. Mar. Biol. Ecol., 42: 71-85.

Yamamoto, Y.; Honda, K. and Tatsukawa, R. (1987). Heavy Metal Accumulation in Antarctic Krill *Euphausia superba*. Proc. NIPR Symp. Polar Biol., 1: 198-204.

BACTERIAL HYDROCARBON DEGRADATION IN ANTARCTICA

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The use of non-renewable fossil energy resources including petroleum hydrocarbons has increased dramatically in the last century. This demand was accompanied by an increase in the production of water insoluble wastes with high toxicity and long half-life in the environment. These wastes generate the problem of their treatment. In addition, the increased demand for hydrocarbons has determined a higher number of accidents, which have spilled in lands, oceans and coasts a great volume of pollutants. Hydrocarbons may be removed from the environment in a variety of physical, chemical and biological ways. Bacterial attack can be an important process in some environments and specific strains have been investigated to assess their capabilities to degrade particular compounds. Today, bacterial bioremediation techniques offer new possibilities to accelerate degradation of pollutants, either by adding the appropriate nutrients required by the naturally occurring microorganisms (Mills & Frankenberger Jr. 1994) or by seeding pure or mixed cultures of bacteria having the metabolic pathways that permit a faster metabolisation of the contaminant (Liu & Suflita 1993). In order to develop the bioremediation techniques, a knowledge of the taxonomic and physiological characteristics of the bacterial strains potentially useful in these processes is essential. In Antarctica, the permanently low temperatures and the scarce previous exposure to anthropogenic hydrocarbons may suggest a low rate of response by the indigenous microflora exposed to crude oil or its derivates (Delille & Vaillant 1990). The continuing human presence in this area generates a potential risk of pollution through the activity of scientific stations, fishing activities and tourist ships (Platt et al. 1981). The wreck of the Bahia Paraiso on Anvers Island in 1989 is a recent example of marine pollution by hydrocarbons. In this paper we summarise investigations of the last five years that comprise: I) Isolation and characterisation of a psichrotrophic Antarctic bacterial strain able to degrade hydrocarbons (ADH-1 strain), II) Studies on the growth of the indigenous microflora and ADH-1 strain in contaminated Antarctic soils under natural conditions. III) Analysis of the distribution of the indigenous hydrocarbon degrading bacteria in Jubany Station.

MATERIALS AND METHODS

I) Isolation and characterisation of a hydrocarbon degrading strain.

Samples were collected in sterile flasks from soils around the gas oil storage tanks of the Jubany Scientific Station (62° 14'S, 58° 40'W) on King George Island (South Shetland Islands).The tanks area is located near the shoreline and soil has been exposed to little spills during oil handling for many years.

Liquid cultures were made in 300 ml Erlenmeyer flasks with 60 ml of sterile saline basal medium (SBM) containing (g/l): NH_4NO_3 4, Na_2HPO_4 8.9, KH_2PO_4 1.8, $MgSO_4.7H_2O$ 0.2, $CaCl_2.2H_2O$ 0.01, $FeSO_4.7H_2O$ 0.01, EDTA 0.01, $CuSO_4.5H_2O$ 0.03, $ZnCl_2$ 0.01 at pH 7.5. For the enrichment procedure 1% v/v of Crude oil was added to SBM as sole carbon source. Suspensions of soil samples (0.1 g/ml) vigorously shaken were used as inoculum (1% v/v) and the cultures were incubated on a rotatory shaker at 250 rpm and 20°C during 72 h. Four subcultures were made under the same conditions and serial dilutions of the last culture were plated on a non selective nutrient agar and incubated at 20°C in order to recover all the strains capable of growing in the crude oil medium. Colonies obtained were isolated and purified by re-streaking twice. The selection of the strain (*Acinetobacter* ADH-1) was based on growth of the isolated strains in SBM with n-hexadecane as sole carbon source under the same conditions described above. In addition, crude oil degrading capacity was tested on microtitre plates with the Hanson et al. (1993) technique based on the colour change of the electron acceptor 2,6-dichlorophenol indophenol (DCPIP). All isolates were tested for morphology and mobility, oxidase and catalase production, Gram reaction, O-F test, pigment production and spore formation. Flagella insertion was examined in all mobile strains. Gram-negative strains were identified at genus level using the scheme of Shewan (1971). In addition, the selected strain was identified at species level with the Rapid NFT kit of API System, MINITEK System and additional biochemical tests.

The effect of initial pH, incubation temperature, NaCl concentration and chemical structure of the substrate on growth of *Acinetobacter* ADH-1 was analysed in liquid culture. Pure and complex mixtures of hydrocarbons were tested as growth substrate: n-hexadecane, n-dodecane, n-heptane, n-hexane, cyclohexane, pyrene, xylene, crude oil, aromatic diesel-oil, hydrogenate diesel-oil and kerosene (In all cases hydrocarbon concentration was 2% except in pyrene and xylene cultures where 0.1% was used). In all assays, duplicate flasks and a sterile control were collected at different times and the remaining hydrocarbon was extracted twice with Cl_2CH_2 (10 ml). Hydrocarbon concentration was measured in these extracts by gas chromatography. Biomass was estimated by a modification of the Hug & Fiechter (1973) technique: after two consecutive extractions of the hydrocarbon with a solvents mixture (ethanol-chloroform-buthanol, 10:1:10, and a ratio of medium volume to solvent volume of 6:1) biomass was evaluated by dry weight (triplicate samples, 24 h at 105°C). This procedure was necessary because ADH-1 showed a heterogeneous growth in liquid media forming macroscopic complexes in association with the hydrocarbon drops due to the high cell surface hydrophobicity.

Surface tension of the culture medium during the growth was measured in triplicate with a Fisher surface tensiometer. To determine whether the selected strain harbours plasmids, DNA was isolated by the Birnboim and Doly (1979) procedure and then separated by agarose gel electrophoresis.

II) Diesel-oil biodegradation in Antarctic soils.

Soil was collected in Potter peninsula, far from the Station to minimise the presence of anthropogenic hydrocarbons. Anyway, initial hydrocarbon content was determined by extraction in Cl_4C and quantification by FT-IR spectrometry as described in EPA 418-1 (U.S.EPA, 1983). Soil was sieved (2 mm diameter) and characterised in terms of texture, water content, pH and C, P and N concentration. Six one-litre sterile flasks were filled with 250 g (2.5 cm height) of soil contaminated with 1.5% w/w diesel-oil. An additional control flask was maintained uncontaminated. Nitrogen (1800 mg/kg) as $NaNO_3$ and Phosphorous (500 mg/kg) as Na_2HPO_4 were added in two flasks to evaluate the influence of a high level of these nutrients (C:N:P ratio 100:12:3) on the growth of the indigenous microflora alone or mixed with the ADH-1 strain. The pH of the soil was maintained, when necessary, at the initial value by addition of sterile 0.1 M NaOH solution. One flask was not pH controlled. Abiotic control flask was prepared by addition of 1g of $HgCl_2$ to the contaminated soil. When ADH-1 strain was inoculated, it was suspended in 0.9% NaCl, adjusted to 0.3 optical density and mixed (3 ml of the suspension) with 250 g of soil. In order to know the inoculum size, samples of ADH-1 suspension were diluted and plated in nutrient agar (Merck). Colony forming units (CFU) were calculated resulting in $6.1x10^8$ UFC/ml. The different assayed conditions are summarised in Tab. 1.

Table 1. Different conditions assayed with the Antarctic soil (250 g) in 1 litre flasks during the 51 days degradation test. ADH-1 suspension used to inoculate the soil contained $6.1x10^8$ CFU/ml.

Condition	$HgCl_2$ (g)	Diesel-oil (ml)	pH Control	N added (mg/kg)	P added (mg/kg)	ADH-1 (ml)
C_1	-	-	-	-	-	-
C_2	1	5.2	-	-	-	-
1	-	5.2	-	-	-	-
2	-	5.2	+	-	-	-
3	-	5.2	+	1800	500	-
4	-	5.2	+	-	-	3
5	-	5.2	+	1800	500	3

Flasks were exposed to the hard "in situ" conditions during 51 d (between January 1 and February 20, 1996). Samples for determination of total hydrocarbon content were taken at the start of the experiment and, subsequently at 10 d intervals. Samples were stored in glass vials, frozen at -20°C and hydrocarbons content determined by the technique mentioned above. The pH of the soil was measured as recommended by Seppelt (1992) every 4 d. Total heterotrophic aerobic bacterial counts (THABC) were estimated every 7 d in nutrient agar plates. Plates were incubated at room temperature (10°-14°C), counted after 14 d and re-checked at 21 and 30 d for changes in CFU number. Hydrocarbon degrading bacterial counts (HDBC) were estimated every 7 d using the same dilutions prepared to determine THABC by seeding on agarised SBM with diesel-oil (2% v/v) as sole carbon and energy source. Plates from initial time, 14 d (time where the THABC showed the highest values in the more efficient conditions) and 51 d (final time) were selected to estimate the generic composition of the bacterial flora. Thirty colonies of each sample were picked at random, purified by re-streaking and classified as was described above. In addition, Sensident test (Merck) was used with all the Gram negative strains. Climate conditions during the assay were recorded by the synoptic meteorological office located in Jubany Station.

III) Distribution of the hydrocarbon degrading indigenous bacterial flora.

Sixteen points were determined on the area of Jubany Station. Some of these were located near the fuel tanks or were chronically exposed to human activity while others were chosen far from human influence. Other samples were taken along the area where a diesel-oil spill had occurred at the end of 1995. In all sites, soil samples were taken and a small fraction was used to determine THABC and HDBC using the above described methods. The rest of the soil samples were frozen at –20°C and transported to our laboratory where total hydrocarbon concentration (THC) was determined by FT-IR spectrometry. Up to now, samples were taken on two occasions: in January 1996 (two months after spill) and in January 1997 in order to analyse the effect of the spill on the normal bacterial flora.

RESULTS

I) Isolation and characterisation of a hydrocarbon degrading strain.

From the enrichment cultures 10 strains were obtained. Taxonomic analysis showed 7 *Pseudomonas* spp, 2 *Acinetobacter* spp and 1 *Flavobacterium* sp. On the basis of growth capacity on SBM with n-hexadecane as carbon source, one *Acinetobacter* strain (ADH-1) was selected for further studies. The physiological and nutritional characteristics of the ADH-1 strain are listed in Tab. 2. Based on the results obtained, ADH-1 was classified as *Acinetobacter lwoffi.*

Table 2. Biochemical and nutritional characteristics of the Antarctic strain *Acinetobacter* ADH-1.

Gam reaction	-	Maltose	-
Oxidase	-	Sucrose	-
Catalase	+	Xilose	-
Voges Proskauer	-	Urease	+
Motility	-	Indole	-
D-glucose (aerob.)	+	Nitrate reduction	-
D-glucose (anaerob.)	-	Starch hydrolysis	-
Growth in 2.5% NaCl	+	Phenylalanine	-
Growth in tween 80	+	Growth at 4°C	+
Growth at pH 5.6	+	Tryptophanase	-
Growth in Mc Conkey	-	Esculine hydrolysis	-
Arginine Dihydrolase	-	Gelatine liquefaction	-
Lisine decarboxilase	-	Arabinose	+
Ornitine decarboxilase	-	Mannitol	+
β-Galactosidase (PNPG)	-	Maltose	+
D-mannose	+	Gluconate	+
N-acetyl D-glucosamine	+	Malate	+
Caprate	-	Acetate	+
Adipate	-	Spore formation	-
Citrate	+	Methyl red	-
SH2 production	-	Phenyl-acetate	-

The effect of the initial pH of the culture medium on the growth of ADH-1 with n-hexadecane is shown in Fig. 1. Significant differences were not observed at initial pH values of 7.0, 7.5 and 8.0 either in the biomass production or in the specific growth rate (μ), the valuesof which ranged around 0.04 h^{-1}. At an initial pH of 6.5 the growth was lower than at higher pH values, and at pH 6.0 the biomass was three folds lower than in the neutral or alkaline pH range.

NaCl concentration can exert a strong influence on the growth and degradation capability of the bacterial strains, and the knowledge of the optimum values is essential if any application to bioremediation in marine or high saline environments is being considered. Fig. 2 shows the growth of ADH-1 at different NaCl concentrations on n-hexadecane. While the best growth was observed at low NaCl concentration, values as high as 3.5% permitted an important biomass formation (1.3 g/l after 165 h). No appreciable growth was observed at 5% NaCl.

Temperature had a marked effect on the growth of ADH-1 (Fig. 3). At 25°C and 30°C no growth differences were observed with n-dodecane as carbon source, maximal biomass ranged between 1.74 g/l (at 25°C) and 1.84 g/l (at 30°C) and μ was similar at both temperatures (0.030 h^{-1} and 0.031 h^{-1} respectively). At 20°C, the biomass as well as μ showed slightly lower values (1.50 g/l and 0.028 h^{-1} respectively). At 5°C and 10°C a long lag period was observed which was longer at 5°C. The biomass achieved at the end of the analysed period (165 h) was similar at both temperatures (0.75 g/l at 5°C and 0.80 g/l at 10°C) and showed much lower values than those observed at the other culture temperatures studied. Growth of ADH-1 at different temperatures is shown with n-dodecane as carbon source because this n-alkane has a melting point (m.p.) of -9.6°C which permits us to incubate cultures at any temperature above 0°C whereas n-hexadecane, with a m.p. of 18.2°C does not permit us to compare the growth at low and moderate temperatures. At any rate, at 20°C, growth rate was very similar in n-dodecane and n-hexadecane as carbon sources and significant differences were not observed in the substrate consumption rate during the growth under both conditions. Despite the extent of hydrocarbon metabolization, the observed growth yield (Yx/s) of this strain never reached values higher than 0.3 (Yx/s from n-hexadecane at 96 h was 0.28 and from n-dodecane at 78 h was 0.21) suggesting that an important fraction of the chemical energy from hydrocarbon molecules either was consumed in other metabolic activities than biomass synthesis, or remained in the culture as only partially degraded metabolites. This comment is based on the knowledge of the high growth yield that can be achieved by some bacteria growing on highly reduced substrates such as hydrocarbons (Wagner et al. 1969).

Strain ADH-1 grew heterogeneously and macroscopic cellular arrangement in association with hydrocarbons could be observed in liquid culture. In order to investigate the production of surface-active compounds, we analysed the evolution of surface tension (S.T.) in cultures of ADH-1 with n-hexadecane (Fig. 4). The culture broth showed a rapid decrease in S.T. (31 din/cm) at early stages of the culture and maintained these low values all along the analysed period. When the broth was divided into a cell free supernatant and a cellular fraction resuspended in water, we observed (Fig. 4) that surface activity was associated principally with the cellular fraction, which showed very similar S.T. values compared with those from the culture broth.

We have found that ADH-1 grows not only on middle chain-length alkanes, but also on complex mixtures as crude oil, hydrogenated diesel-oil, aromatic diesel-oil and kerosene. A preliminary analysis showed no ability to grow on aromatic hydrocarbons such as pyrene and xylene. In addition, no appreciable growth was observed on short chain alkanes (octane and shorter). No plasmids were found in this strain by agarose 0.7% gel electrophoresis, either in cells cultured in the presence of hydrocarbons or in cells cultured in nutrient broth.

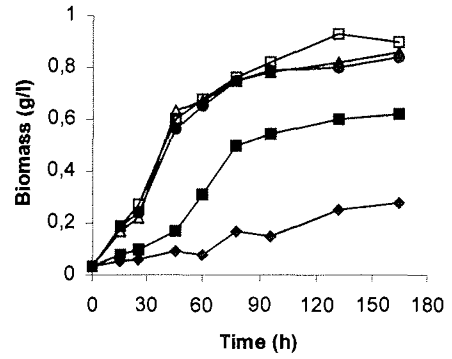

Figure 1. Effect of initial pH on the growth of ADH-1 at 20°C with C_{16}. ◆:pH 6.0. ■: pH 6.5. ● :pH 7.0. □: pH 7.5. Δ: pH 8.0

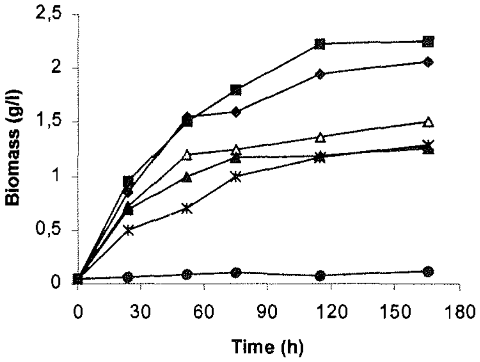

Figure 2.Growth of ADH-1 at 20°C with C_{16} and different NaCl concentrations.◆:0%. ■: 0.5%. Δ: 1.0%. ▲: 2.0 ✱: 3.5%. ●: 5.0%.

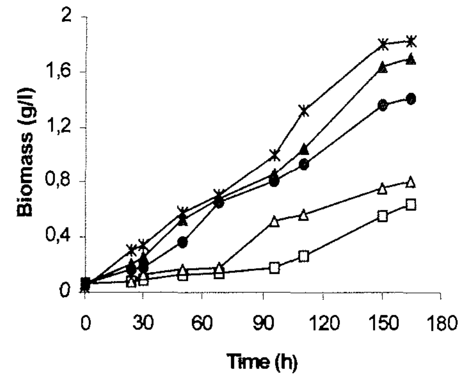

Figure 3. Effect of culture temperature on growth of ADH-1 strain with C_{12} as carbon source. □: 5°C. Δ: 10°C. ●: 20°C. ▲: 25°C. ✱: 30°C.

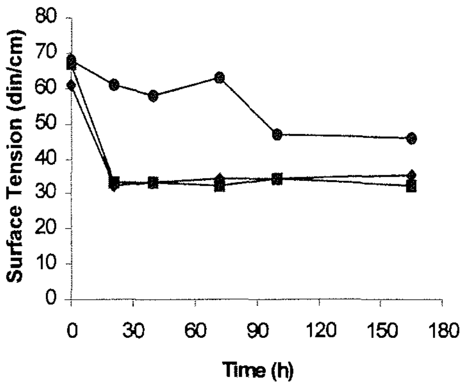

Figure 4.Surface tension values in ADH-1 cultures. ◆: from the total broth with C_{16}. ●: from the cell free supernatant. □: from cellular fraction resuspended in water.

II) Diesel-oil biodegradation in Antarctic soils.

Characterisation of soil showed the following results: pH, 7.10; water content, 10%; total C, 0.51%; total N, 0.054%; direct distillable N, 45.1 ppm; P,14.6 ppm; sand, 93.3%; silt, 4.00%; clay, 2.7%.
Maximum, minimum and average values of the main climate parameters during the 51 d of the study are summarised in Tab. 3.

Table 3. Main climatic parameters during the experimental period. Soil microorganisms were exposed to these extreme environmental conditions all along the assay.

		JANUARY	FEBRUARY (until day 19th)
Temperature (°C)	average	+2.10	+2.88
	maximum	+10.10	+8.40
	minimum	-1.40	-2.00
Relative Humidity (%)	average	89.84	92.02
	maximum	100.00	100.00
	minimum	62.00	63.00
Wind speed (knots)	average	19.82	19.03
	maximum	60.00	50.00
	minimum	0.00	0.00
Cloudiness (0-8)	average	6.85	6.05
	maximum	8.00	8.00
	minimum	0.00	0.00

THC in the different assayed conditions is shown in Fig. 5. During the first 10 d of the study (the values of which are not showed), an important decrease in the hydrocarbon concentration was observed in all cases, including the abiotic control. This fact, that led the initial value of THC in the soil from 14380 ppm at 0 d to the values observed in Fig.5 at 10 d, could be related to the volatilisation and stripping rates of the most volatile compounds of the diesel-oil, determined by the high speed of the predominant winds in the area. During the rest of the study, indigenous microflora produced a significant decrease in the THC compared with the abiotic control. In addition, an important decrease in the THC was observed when ADH-1 strain was inoculated to the soil at an initial concentration of $6.4x10^6$ CFU/gr. It is important to remark that one day after the start of the study, bacterial concentration in the flask where ADH-1 strain was inoculated (flask 4) was $4.9x10^6$ CFU/ml indicating that a fraction of inoculum does not survive the inoculation. The addition of N and P determined higher values of remanent THC whenever this nutrients were added compared with the corresponding non supplemented condition (Fig. 5). No significant differences were observed with or without pH control (data not shown).

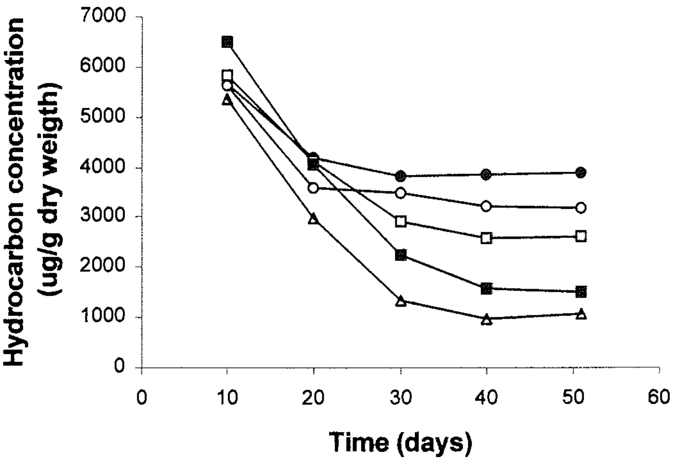

Figure 5. Total hydrocarbon concentration in the different assayed conditions using contaminated Antarctic soil. ●: abiotic control. □: contaminated soil. ○: contaminated soil + N and P. △: contaminated soil + ADH-1. ■: contaminated soil + ADH-1 + N and P. Initial concentration, at t=0 was 14380 ppm (not shown). See details in the text and table 2.

THABC of the soil used in this study was $2.2x10^6$. After the addition of $HgCl_2$ to the abiotic control, no counts were detected in any sample all along the study. Evolution of the THABC values in the different assayed conditions are shown in Fig. 6, where the first point represents the counts obtained in day 1, 24 h after addition of the different components of each assayed condition. The presence of diesel-oil in the soil determined an increase in the bacterial counts (compared with the uncontaminated control) that was significant at 28 d. In accordance with what was observed in figure 5 with the THC, the addition of N and P produced an important loss in viability of both, the ADH-1 strain and the indigenous flora, showing a minimum at 7 and 14 d respectively and reaching similar values to the control at the end of the study. This effect seems to affect more dramatically to indigenous microflora than the ADH-1 inoculated soil.

HDBC along the study are shown in Fig. 7. Uncontaminated soil showed an initial level of $7x10^4$ CFU/g that represented a 3.2% of the THABC, this fraction, that remained approximately constant during the analysed period was similar to other reported non Antarctic soils (Miethe et al., 1994, Ferrari et al., 1994). Addition of diesel-oil produced an important increase in the HDBC of the soil determining that, between 21 and 28 d, almost the total bacterial flora were represented by hydrocarbon degrader microorganisms (between 85 and 100%). The maximum value of HDBC occurred at 28 d ($8.4x10^6$ CFU/g) and a slow decrease until the end of the study was observed. When ADH-1 strain was added to the contaminated soil, HDBC raised faster and reached a maximum earlier than the autochthonous microflora ($2.7x10^7$ CFU/g at 21 d) reducing the acclimation period showed by the indigenous flora, even though the maximal biomass value was only slightly higher than that observed in the contaminated control. The effect of the N and P on the HDBC was similar to the one observed with the THABC and a significant difference was observed between the supplemented and non supplemented conditions as much in the indigenous flora as in the ADH-1 supplemented flask. (Fig. 7).

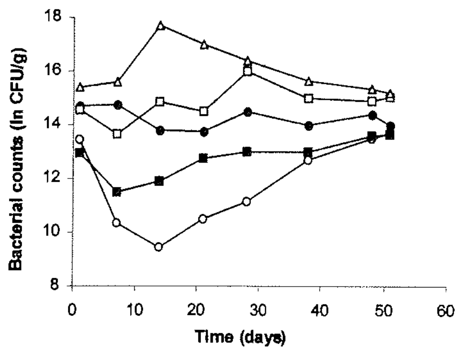

Figure 6. Heterotrophic aerobic bacterial counts in soil from the different assayed conditions. •: uncontaminated soil. □: contaminated soil. ○: contaminated soil + N and P. Δ: contaminated soil + ADH-1. ▪: contaminated soil + ADH-1 + N and P. See details in the text and table 2.

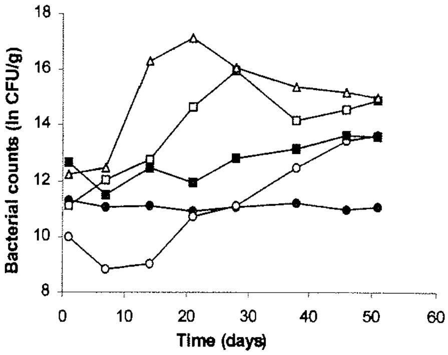

Figure 7. Hydrocarbon degrader bacterial counts in soil from the different assayed conditions. •: uncontaminated soil. □: contaminated soil. ○: contaminated soil + N and P. Δ: contaminated soil + ADH-1. ▪: contaminated soil + ADH-1 + N and P. See details in the text and table 2.

Taxonomic analysis of the bacterial flora from the different assayed conditions at 0, 14 and 51 d showed an important diversity of the THABC in the uncontaminated soil with *Agrobacterium* (23%), *Pseudomonas* (15%) and an unidentified Gram(-) cocci (15%) as predominant groups. In addition, *Acinetobacter*, *Flavobacterium*, *Bacillus*, *Micrococcus*, *Xanthomonas* and *Moraxella*, were present. This pattern was observed unchanged along the study in the uncontaminated soil (C_1 flask). In contrast, HDBC of the uncontaminated soil were represented only by *Pseudomonas* (88%), *Acinetobacter* (10%) and Coryneforms (2%).

Hydrocarbon addition dramatically reduced the THABC diversity of the soil (Fig.8) leading to the total predominance of the genera *Pseudomonas* (50%) and *Acinetobacter* (50%). At the end of the analysed period, when the THC was reduced appreciably, bacterial diversity seemed to tend to the initial pattern. HDBC of the contaminated soil (Fig.9) showed a total dominance of *Pseudomonas* and *Acinetobacter* but, in contrast with the uncontaminated soil, in this case *Acinetobacter* tended to increase during the experiment. Presence of N and P produced important changes in the distribution of the THABC leading to a predominance of *Acinetobacter* spp in detriment of *Pseudomonas* spp compared with the non supplemented contaminated soil and determining a decrease in the biodegradation capacity.

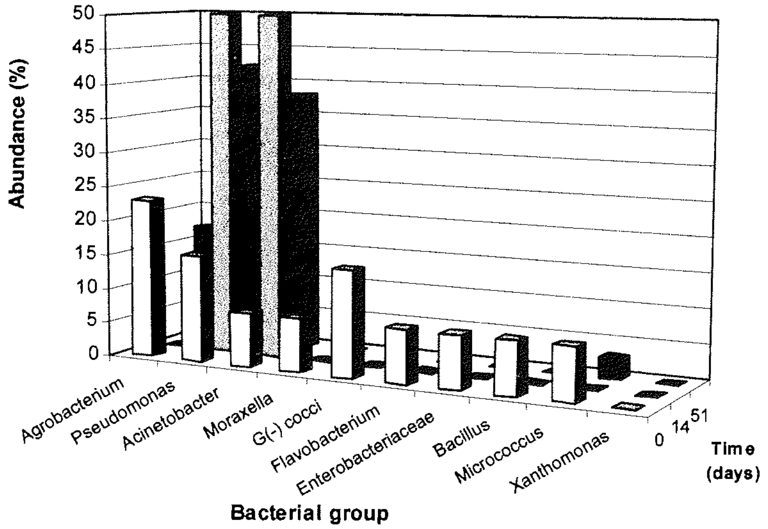

Figure 8. Taxonomic analysis of the total heterotrophic aerobic bacterial flora isolated from the contaminated soil at 0, 14 and 51 days.

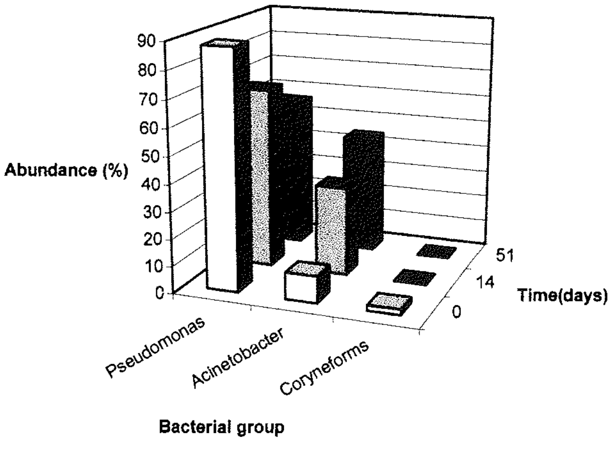

Figure 9. Taxonomic analysis of the hydrocarbon degrading bacterial flora isolated from the contaminated soil at 0, 14 and 51 days.

III) Distribution of the hydrocarbon degrading indigenous bacterial flora.

In relation to the results obtained from the soil samples with different pollution degree, the following general results have been obtained: a) Areas far from the human influence showed a low THC (less than 90 ppm) and a low percentage of HDBC (between 2 and 4% of the THABC). These values had not changed one year later, when the second sampling was made. b) Chronically exposed areas showed high values of THC (i.e. 686 ppm near the generators or 272 ppm near the fuel storage tanks) and high percentages of HDBC (94% and 45% respectively). This situation was similar one year later. c) Not chronically exposed areas that were directly affected by the diesel oil spill, showed two months after the accident, very high THC values and almost the total bacterial flora was represented by hydrocarbon degrading microorganisms. This situation showed significant changes one year later suggesting an important recovery capacity of the authocthonous bacterial flora. As an example of the above commented, the soil sampled just in the area where the spill flowed two months before , showed a THC of 2787 ppm and 92% of HDBC. The same area, one year later had a THC of 142 ppm and a HDBC percentage of 20%. Although we did not make the taxonomic analysis of the bacterial flora in this study, results suggest that the indigenous bacterial flora of the soil affected by the diesel-oil spill could be responding in a similar way to the observed in the flask experiments carried out in "in situ" conditions.

CONCLUSIONS

The results exposed here, summarise the laboratory and field biodegradation researches carried out in Antarctica during the last years. In this continent, no success in bioremediation processes could be achieved using non-psychrotrophic microorganisms. Isolation of ADH-1 was the first step in the design of these processes. In relation to the physiological characteristics of ADH-1, the range of pH tolerance and the high salt tolerance (Fig. 2) makes it potentially adequate to decontaminate marine and coastal polluted sites. According to the definition of Morita (1975), ADH-1 is a psychrotrophic (and not a psychrophilic) microorganism with optimum growth temperature above 20°C but capable of growing at near 0°C temperatures (Fig. 3). This is not surprising because as has been reported previously (Delille & Perret 1989, Mac Cormack & Fraile, 1990), a large part of the coastal Antarctic bacterial community appear to be psychrotrophic rather than psychrophilic. The incapacity to degrade short chain length alkanes is a common feature in hydrocarbon degrading *Acinetobacter* strains and only a few have been reported having the ability to grow on decane or shorter alkanes (Asperger & Kleber 1991).

Soil biodegradation studies carried out in flasks exposed to the Antarctic climate conditions, showed that while the abiotic factors determined a significant elimination of hydrocarbons, a fraction remained undegraded despite the important biodegradation activity showed by the indigenous microflora. In presence of the ADH-1, highest biomass values were reached earlier and the final hydrocarbon content was significantly lower than the uninoculated control. These results make this strain potentially useful to improve the biodegradation capacity of soil microflora. Growth inhibition produced by P and N levels used in this study, that have been indicated as growth promoters by others (Mills & Frankenberger Jr, 1994), highlights the different responses of the diverse bacterial populations and shows that the use of P and N as enhancers of the bioremediation must be carefully analysed. Uncontaminated Antarctic soil showed an important bacterial diversity but only *Pseudomonas* and *Acinetobacter* were able to degrade hydrocarbons. This is in agreement with research developed far from Antarctica and suggest that, despite the physical and chemical conditions, these genera are the most efficiently adapted to hydrocarbon polluted environments. Diversity of THABC is deeply affected by the presence of diesel oil (Fig.8). In this condition, only the hydrocarbon degrading genera were present, showing a similar pattern to that observed in the HDBC under the same condition (Fig.8 and 9).

Finally, the distribution of the bacterial flora and the hydrocarbon concentration observed in Jubany Station indicates, on one hand the important role of the indigenous microflora in the degradation of the pollutants and on the other hand, the dramatic effect of the hydrocarbons on the bacterial flora that, one year later, still showed (however reduced) the effects produced by the oil spill.

REFERENCES

Asperger, O. & Kleber, H.P. 1991. Metabolism of alkanes by *Acinetobacter*. In: Towner, K.J. ed. The biology of *Acinetobacter*. New York: Plenum Press, 1-24.

Irnboim, H.C. & Doly, J. 1979. A rapid alkaline extraction procedure for screening recombinant plasmid DNA. Nucleic Acid Res., 7, 1513-1523.

Delille, D. & Perret, E. 1989. Influence of temperature on the growth potential of southern polar marine area. Microbial Ecol., 18, 117-123.

Delille, D. & Vaillant, N. 1990. The influence of crude oil on the growth of subantarctic marine bacteria. Antarct. Sc., 2, 655-662.

Ferrari MD, Albornoz C and Neirotti E.1994. Biodegradabilidad en suelos de hidrocarburos residuales en fondos de tanques de almacenamiento de petróleo. Rev. Arg. Microbiol. 26, 157-170.

Hanson, K.G., Desai, J.D. & Desai, A.J. 1993. A rapid and simple screening technique for potential crude oil degrading microorganisms. Biotechnol. Techniques, 7, 745-748.

Hug, H. & Fiechter, A. 1973. Assimilation of aliphatic hydrocarbons by *Candida tropicalis*. I-Analytical problems in hexadecane batch experiments. Archiv fuer Mikrobiologie, 88, 77-86.

Liu, S. & Suflita, J.M. 1993. Ecology and evolution of microbial populations for biorremediation. Trends in Biotechnol., 11, 344-352.

Mac Cormack, W.P. & Fraile, E.R. 1990. Bacterial flora of newly caught Antarctic fish *Notothenia neglecta*. Polar Biol., 10, 413-417.

Miethe D, Riis V and Babel W.1994. The relationship between the microbial activity of the autochtonous microorganisms of pristine and contaminated soils and their ppotential for the degradation of mineral oil hydrocarbons. Acta Biotechnol 14, 131-140.

Mills S.A. and Frankenberger Jr W.T.1994. Evaluation of phosphorus sources promoting bioremediation of diesel fuel in soil. Bull. Environ. Contam. Toxicol. 53, 280-284.

Morita, R.Y. 1975. Psychrophilic bacteria. Bacteriological Rev., 39, 144-167.

Platt, H.M., Mackie, P.R., Clarke, A. 1981. Sources of Antarctic hydrocarbons. Mar. Poll. Bull., 12, 407-410.

Seppelt, R.D. 1992. Assesment of environmental impact, 4pp. In Wynn Williams, D.D. ed. BIOTAS Manual of methods for Antarctic Terrestrial and Freshwater Research. Scientific Comittee on Antarctic Research, Cambridge.

Shewan, J.M. 1971. The microbiology of fish and fishery products. A progress report. J. Appl. Bacteriol., 34, 299-315.

U.S. Environmental Protection Agency. 1977. Serial N° 95-12. U.S. Gov. Printing Office, Washington, D.C.

Wagner, F., Kleemann, T.H. & Zahn, W. 1969. Microbial transformation of hydrocarbons. II. Growth constants and cell composition of microbial cells derived from n-alkanes. Biotechnol.Bioeng., XI, 393-408.

UV-absorbing compounds in surface waters of Potter Cove: Preliminary Results.

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Recent stratospheric ozone depletion (Kerr, 1994) has led to an increase of ground level ultraviolet-B radiation (UV-B, 280-320 nm) over Antarctica (Frederick, 1997). Increased UV-B radiation has been reported to be harmful to aquatic organisms by inducing DNA damage (Karentz et al., 1991), photodamage (Bischof et al. 1998) or interfering with a variety of basic processes like primary production (Prèzelin et al., 1994), nutrient assimilation (Döhler, 1991), and ATP formation (Vosjan et al., 1990). UV-B induced damage has been found on various organismic levels from bacteria (Herndl et al., 1993) to multicellular organisms (e. g. zooplankton, Williamson et al., 1994). Significant UV-B induced modifications of trophic interactions have also been described (Bothwell et al., 1994). Among the adaptive responses of organisms to increasing UV-B, the accumulation of photoprotective substances like mycosporine-like-aminoacids, (MAAs) is among the best studied ones. These compounds could act as sunscreens, potentially alleviating deleterious UV-B effects (Karentz et al., 1991, Adams & Shick 1996, Karsten et al. 1998).

During the Austral spring 1995, we measured MAA concentrations in surface waters of Potter Cove (King George Island) to study the role of these sunscreening compounds in phytoplankton photobiology during the time of the Antarctic ozone hole period. Our objective was to see whether MAA-accumulation is part of the adaptive response of planktonic microorganisms to UV-B irradiance in Antarctic surface waters. Our null hypothesis was that UV-B does not correlate with the presence of MAAs in the natural environment of Potter Cove.

UV-B radiation (J m^{-2}) was integrated every 5 min with a 311 nm sensor ($\Delta\lambda$ = 1nm) with an automatic meteorological station (Delta Logger model LS2). The logger was installed in the proximity of the Station Jubany-Dallmann, 10 m above sea level. Daily data were integrated between midnight and noon (0 - 12.00h) following the Simpson´s rule for further analyses.

Daily water sampling at a permanent station (35 m depth) located 200 m off the southern coast in the inner part of Potter Cove was performed from November 17 to December 10 1995 at noon (12.00h). Since, due to the high loads of suspended particulate matter from terrigenous input, the euphotic layer in the inner cove is shallow (around 5 m depth, see Fig. 4), UV-B penetration into the water column was assumed to be small. Therefore, mainly surface water samples were collected with Niskin bottles. Storms interrupted sampling during 5 days, so that a total of 18 samples was obtained throughout the whole sampling period. In addition, a vertical profile (0, 5, 10, 20 and 30 m depth) was sampled on December 10.

Treatment of the samples: Directly after collection, the samples were splitted for MAA, particulated organic carbon and nitrogen (POC and PON) and chlorophyll *a* measurements. Different volumes of seawater were filtered for each parameter (1000 ml, 200 ml and 1000-1500 ml, respectively) through precombusted Whatmann GF/F filters at around 450 mm Hg vacuum pressure. After that, the filters were kept frozen (-20° C) until analysis. Chlorophyll *a* concentrations were measured directly in the Dallmann laboratory, filters for MAA and POC analysis were frozen to -20°C and shipped to the Alfred Wegener Institute in Bremerhaven.

Analytical procedures: MAAs were extracted twice with a total volume of 15 ml of 25% methanol in water at 45°C. After centrifugation (5 min, 5000g) and evaporation of the extraction medium under vacuum, MAAs were redissolved in 300 µl 100 % methanol and analyzed by RP-HPLC according to Karsten and Garcia-Pichel (1996). Shinorine was identified from its absorption spectrum. Further three unknown MAA compounds were separated. Quantification was done using the molar extinction coefficient $\varepsilon_{\mathrm{mmol\ l^{-1}}}$ 1325.3 for shinorine. Data were normalized to POC and to chlorophyll a. CN-content of particles on precombusted GFF-filters were measured using a Carlo-Erba CHN 1500 autoanalyzer. Filters were pre-dried at 60°C for 2 days.

Chlorophyll a was measured in 90 % acetone extracts, following the protocol and formulae given by Strickland and Parsons (1972), and using a Shimadzu spectrophotometer. Data were corrected for phaeopigments.

Pearson product-moment regression and correlation analyses were used. Data were log transformed to meet the normality and homoscedascity requirements of these statistical techniques.

Phytoplankton abundance was very low during the whole survey, as inferred from the low chlorophyll a water concentrations ranging between 1-15 mg m^{-2} (Fig. 1; see also Schloss et al. this issue). These results were corroborated by cell counts (Schloss, 1997). The assemblages were dominated by small pennate diatoms and phytoflagellates, including *Cryptomonas sp.*. The low phytoplankton biomass was attributed to the alternation of periods of vertical mixing (strong winds) with times where stratification could build up in the water of the cove and high sediment particle concentrations in the water surface caused reduction of the light intensities and of the euphotic depth (Schloss, 1997).

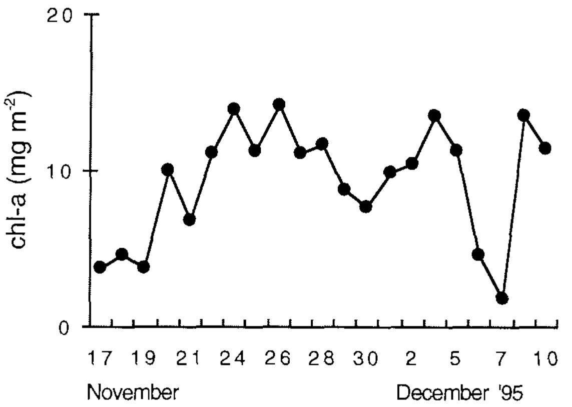

Fig. 1: Daily variation of depth integrated chlorophyll *a* concentration in the water column (0-30 m) of Potter Cove between November 17 and December 10, 1995.

HPLC analysis indicated the presence of Shinorine as well as 3 unknown MAA components (M322, P334 and M336) in the surface waters of Potter Cove. Since the microscopical examination of the samples did not show significant amounts of zooplankton, we assumed that most of the MAAs detected originated from phytoplankton. The time series of both UV-B radiation and total MAA concentration normalized to POC showed similar trends, with maximum values observed at the beginning of the survey (Fig. 2). A significant correlation was found between total MAA ($R = 0.51$; $P < 0.05$) concentration and M336 ($R = 0.50$; $P < 0.05$) with incident UV-B radiation, whereas M322 and M334 did not follow the same trend ($R = -0.459$, $P > 0.05$ and $R = 0.079$, $P > 0.05$, respectively). The latter compounds were generally found at lower concentrations than Shinorine and M336, and, during several days, were below detection limit.

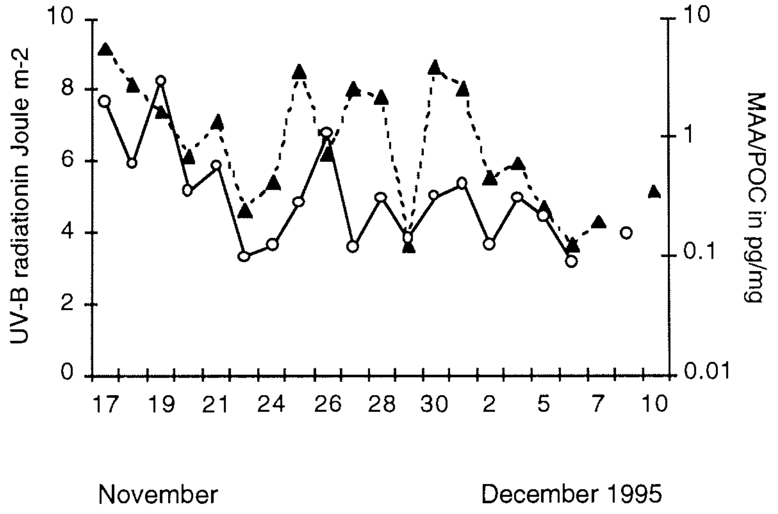

Fig. 2: Daily variation of total MAA concentration normalized to POC (pg mg^{-1} **O**) and daily UV-B surface radiation (J m^{-2} ▲) at 311 nm ($\Delta\lambda$ = 1nm) integrated over 300 sec.

The density profile (Sigma-t) on to December 10 showed a marked stratification in the water column, with the maximum density gradient between 0-10 m (Fig. 3 a). On the same day, the chlorophyll a maximum was observed in 10 m water depth, reflecting phytoplankton accumulation at the level of the pycnocline (Fig. 3 a). This clearly matched the vertical distribution of total MAAs, but in this case the maximum was located between 5-10 m depth (Fig. 3 b). When MAAs were normalized to chlorophyll a, however, highest relative concentrations were found in the water surface (Fig. 3 b). This indicates that cells exposed to UV in surface waters synthesize higher amounts of sunscreening compounds, compared to cells in deeper waters.

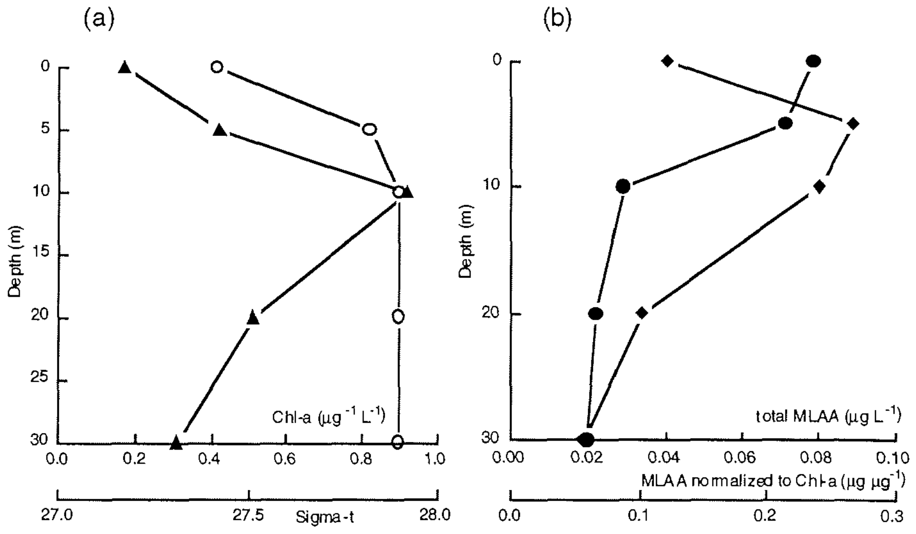

Fig. 3: (a) Vertical distribution of the anomaly of density (Sigma-t ○) and chlorophyll a ($\mu g\ l^{-1}$ ▲); (b) vertical distribution of the total MAAs ($\mu g\ l^{-1}$ ◆) and of MAAs normalized to chlorophyll a ($\mu g\ \mu g^{-1}$ ●).

Several authors suggested that the photoinducibility of MAAs could be related to UV exposure (Dunlap et al., 1986; Karentz et al. 1991, Ferreyra 1995), which is convincing indeed, taken that these substances absorb light in the UV-A as well as the UV-B range. To date, no comparable time series from a marine environment has been reported which relates incident UV radiation to the presence of UV blocking substances in phytoplankton under natural conditions. In an experimental study of cyanobacteria Garcia-Pichel et al. (1993) described the sunscreening functions of MAAs in benthic microalgae.

Although the findings presented here do not provide final evidence of the photoprotective role of MAAs, our null hypothesis could be rejected as there is a significant positive correlation between MAA concentration in surface water microalgae and incident UV-B radiation. Further studies will have to include experimental work, to specify the role of MAAs in photoprotection of phytoplankton in Antarctic coastal ecosystems.

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References

Adams, N. L., J. M. Shick (1996). Mycosporine-like amino acids provide protection against ultraviolet radiation in eggs of the green sea urchin Strongylocentrotus droebachiensis. Photochem. Photobiol. 64 (1): 149-158.

Bischof, K., Hanelt, D., Wiencke, C. (1998). UV-radiation can affect depth-zonation of Antarctic macroalgae. Mar. Biol., in press.

Bothwell, M.L., Sherbot, D.M.J., Pollock, C.M. (1994). Ecosystem response to solar ultraviolet-B radiation: Influence of trophic-level interactions. Science 265:97-100.

Döhler, G. (1991). Uptake of [15N]-Ammonium and [15N]-Nitrate by Antarctic diatoms: dependence on the daytime and effect of UV-B radiation. Biochem. Physiol. Pflanzen 187:347-355.

Dunlap, W.C., Chalker, B.E., Oliver, J.K. (1986). Bathymetric adaptations of reef-building corals at Davies Reef. Great Barrier Reef, Australia. III. UV-B absorbing compounds. J. Exp. Mar. Biol. Ecol. 104:239-248.

Ferreyra, G.A. (1995). Effets du rayonnement ultraviolet sur le plancton des régions froides temprèrès et polaires. PhD Thesis, Univ. of Quebec at Rimouski.

Frederick, J.E. (1997). The climatology of solar UV radiation at the earth's surface. Photochem. Photobiol. 65:253-254.

Garcia-Pichel, F., Wingard, C.E., Castenholz, R.W. (1993). Evidence regarding the UV sunscreen role of a Mycosporine-like compound in the cyanobacterium Gloeocapsa sp. Appl. Environ. Microbiol. 59:170-176.

Herndl, J.G., Muller-Niklas, G., Frick, J. (1993). Major role of ultraviolet-B in controlling bacterioplankton growth in the surface layer of teh ocean. Nature 361:717-719.

Karentz, D., Cleaver, J.E., Mitchell, D.L. (1991). Cell survival characteristics and molecular responses of Antarctic phytoplankton to ultraviolet-B radiation. J. Phycol. 27:326-341.

Karsten, U., Garcia-Pichel, F. (1996). Carotenoids and mycosporine-like amino acid compounds in members of the genus Microcoleus (Cyanobacteria): A chemosystematic study. System. Appl. Microbiol. 19: 285-294.

Karsten, U., Franklin, L. A., Lüning, K., Wiencke, C. (1998). Natural ultraviolet and photosynthetic active radiation induce formation of mycosporine-like amino acids in the macroalga *Chondrus crispus* (Rhodophyta). Planta, in press.

Kerr, R.A. (1994). Antarctic ozone hole fails to recover. Science 266:217.

Prèzelin, B.B., Boucher, N.P., Smith, R.C. (1994). Marine primary productivity under the influence of the Antarctic ozone hole: ICECOLORS'90. In: Ultraviolet Radiation and Biological Research in Antarctica (Weiler, S. & Penhale, P. , eds.). Ant. Res. Ser. 62:159-186.

Schloss, I.R. (1997). Escalas tèmporo-espaciales de variabilidad del fitoplancton costero antártico. PhD Thesis. Univ. of Buenos Aires.

Strickland , J.D.H. , Parsons, T.R. (1972). A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Canada, 2nd edition 167.

Vosjan, J.H., Döhler, G., Nieuwland, G. (1990). Effect of UV-B irradiance on the ATP content of microorganisms of the Weddell Sea (Antarctica). Neth. J. Sea Res. 25:391-393.

Williamson, C.E., Zagarese, H.E., Schulze, P.C., Hargraves, B.R., Seva, J. (1994). The impact of short-term exposure to UVB radiation on zooplankton communities in north temperate lakes. J. Plankton Res. 16(3):205-218.

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