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OCEANOGRAPHIC INVESTIGATION OF THE EZCURRA INLET DURING THE 2nd ANTARCTIC EXPEDITION OF THE POLISH ACADEMY OF SCIENCES (PAS) *

1. GENERAL DESCRIPTION OF INWESTIGATIONS

The Ezcurra Inlet on King George Island was chosen as an experimental area for studies of natural processes in Antarctic coastal waters. This sea area is situated in the vicinity of the „H. Arctowski" PAS Antarctic Station and constitutes a part of the larger Admiralty Bay. The width of the inlet varies from 2 to 3 km, its length is equal to 7 km and its, area is ca 17 km^2. It is surrounded by glacial cascades and steep rocky slopes reaching 300 m in height and sometimes exceeding 400 m (see Fig. 1). The depth of the inlet, as determined by extensive echosounding during the 2nd Expedition, varies from 350 m at its entrance to 100 m and less with a lateral underwater escarpment of an average depth of 80 m in its central part. Near the shores the bottom falls steeply down to 50 m and more. In the central part, behind the escarpment, the rocky Dufayel Island protrudes with a peak of 205 m above sea level. The base of the island measured at sea level covers an area of ca 0.5 km^2.

Oceanographic investigations were carried out on board the M/S „Antoni Garnuszewski" (5500 DWT) commanded by captain Tadeusz Kalicki. The vessel was anchored in the Ezcurra Inlet on the above mentioned underwater escarpment. The depth at the investigation site

* The investigations were carried out under research problem MR-II-16 coordinated by the Institute of Ecology of the PAS.

Fig. 1. General view of Ezcurra Inlet on King George Island during a period of windless weather in February 1978. Glacier fronts, rock edges, Dufayel Island (205 m high) and M/S „Antoni Garnuszewski" (122 m in length, 5500 DWT) anchored at the investigation site are visible

Ryc. 1. Widok ogólny fiordu Ezcurra na wyspie King George w czasie bezwietrznej pogody w lutym 1978 r. Widoczne są czoła lodowców, brzegi skalne, wyspa Dufayel (205 m wysokości) oraz statek M/S „Antoni Garnuszewski" (122 m długości, 5500 DWT) na kotwicy w miejscu badań varied from 65 to over 80 m during movement at anchor. A small auxiliary boat and moored currentmeters were also employed in the measurements.

The research staff comprised specialists in marine physics and chemistry, hydrobiology, hydrometeorology, hydrography and others, as listed at the end of this report. The investigations were carried out thoughout December 20, 1977 — March 10, 1978, excluding a 7 days break in January. The results of extensive measurements and analyses were collected, permitting the determination of environmental factors and course of some processes in the environment investigated.

The present report is a preliminary presentation of characteristic features of the Ezcurra Inlet based on only the part of the data which could be evaluated during the expedition and shortly after its completion. The following parameters were included: meteorological conditions, ice confluence, currents and tides, water salinity and temperature, concentration of oxygen and nutrients, suspensions and water transparency, underwater visibility, solar radiation and underwater lightfield, pigments, phytoplankton and primary production, as well as zooplankton and its bioluminescence.

The detailed evaluation of the data obtained will be the subject of separate papers, after completion of further calculations and analyses. In addition, the results of the biological studies on the elements of the ecosystem and bioenergetics of sea organisms are being evaluated.

2. ENVIRONMENTAL FACTORS AND PHENOMENA IN THE EZCURRA INLET

M e t e o r o l o g i c a l   c o n d i t i o n s in the Ezcurra Inlet during the Antarctic summer of 1977/78 resulted mainly from the general westerly circulation of air masses from the ocean with relatively stationary low pressure area over the Weddel Sea and high pressure area over the Southern Pacific and Southern Atlantic. In addition in the Ezcurra Inlet itself the weather is strongly modified by the presence of an ice cap on King George Island as well as by the position of a deep trough in the Ezcurra Inlet in the direction WSW to the outlet at ENE. The air masses being cooled over the glacier, enter the inlet with increased velocity due to its even slopes resulting in strong downflow winds with all other consequences of föhn phenomena. For this reason the windvelocity changes rapidly and frequently with even small variations of a general atmospheric circulation. The distribution of the probability density of the average wind velocity shows a flat maximum at the level of 0.08 m/s^{-1} in the interval of 6—8 m/s and is noticeably expanded to the higher velocity up to 16 m/s with the probability density ca 0.03 m/s^{-1} and 30 m/s with a probability density of 0.001, m/s^{-1}

(see Fig. 2). In gusts the wind velocity is much higher and occasionally reaches over 40 m/s. Wind directions close to west predominate, especially in the case of strong winds that result from general atmospheric curculation and even slopes of glacier favouring föhn phenomena on the western side of the inlet in contrast to the unpropitious rocks on the other. The trough of the Ezcurra Inlet modifies, to some extent, primary wind direction driving the air flow from the west to the outlet of the fiord.

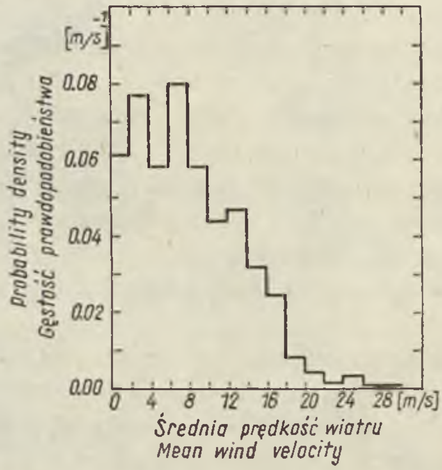


Fig. 2. Statistical distribution of average wind velocity in Ezcurra Inlet for the period of the Antarctic summer 1977/78 (obtained on the basis of measurements taken every 3 hours from December 20, 1977 to March 10, 1978 excluding the period of January 7—13, 1978)

Ryc. 2. Statystyczny rozkład średnich prędkości wiatru we fiordzie Ezcurra w okresie antarktycznego lata 1977/78 (ściśle z pomiarów co 3 h od 20 grudnia 77 do 10 marca 78 z przerwą od 7 do 13 stycznia)

The cloud coverage is usually considerable and very differentiated; the summer, average is close to 7/8, the cloud ceiling most often reaches 200—300 m. The clouds „crawl" on the glacier and part of them originate as a result of the contact of humid ocean air masses with glaciers. At the same time the sky over the inlet is often cloudless due to föhn phenomena. This has a pronounced effect on the underwater lightfield, which will be discussed later.

Air temperatures in summer usually varied in the range from 0 to +4°C (exceptionally to +7°C). Rainfall intensity is moderate, the average relative humidity is ca 80%, barometric pressure is low (the average for February 1978 was equal to 990.5 mbar), the pressure drops and weather changes are frequently rapid, and surface waves acquire stormy character in a dozen or so minutes.

W a v e s and drift currents are symptoms of strong disturbances of water surface in the fiord by the downflow winds. Small dimensions of the fiord however permit to develop waves of a period of up to 4 s and height merely 2.5 m even for hurricanes. The waves are steep and of a complex spectrum due, however, to specific action of the downflow winds and wave deflections from the rocky shores of the inlet. The most frequently occuring waves have maximum heights close to 0.5 m.

Ice bloocks confluence due to their tearing off the glacier is a phenomenon particularly visible and significant for this area. The glacier tongues on steep ice cascade are undermined at the front by fiord waters and do not reach the state of full hanging in the water. For this reason the dimensions of torn off and floating ice blocks are small in comparison with icebergs. The linear dimensions vary from small (fine ice pack) up to about 40 m. The blocks are irregular in shape due to water action. During stills or winds directed to the inside of the inlet the blocks are accumulated near the shores in the interior of the inlet and during favourable winds and surface currents they flow in masses towards its outlet. The intensity of ice covering also depends on an inflow of warm air masses from the ocean, which influences the instantaneous rate of ablation of the glacier. Sometimes even over 20% of the water surface of the inlet is covered with floating ice.

During periods of substantial drift of great masses of jagged ice blocks there is significant danger to small vessels and various technical devices laid in the fiord including measuring instruments lowered from the deck of the research vessel. Observations carried from the „Arctowski" Station indicate that in winter the fiord surface is covered with floe from the glacier, which should rise together with the tidal changes of sea level.

Tides are the factor which markedly impose a certain rhythm on other processes occurring in the inlet. They are irregular, twelve hours in period, disturbed by the shape of the bottom and shores of Admiralty Bay as well as by random hydrometerological conditions. The amplitude of sea level variations attains its maximum values in two--week cycles and then the diurnal variation of sea level reaches 2 m, occasionally exceeding this value.

Water flows, which can be described as tidal currents and superimposed surface drift currents and depth compensation currents, are characterized by strong fluctuations and achieve velocities ranging from 2 cm/s to over 40 cm/s depending on the place, tide phase, power and direction of wind. Flow directions in upper and lower layers of water are different, sometimes opposite, varying in time, indicating complex circulation of adjacent ocean water masses (see Fig. 3). This probably leads to the periodical total exchange of water mass of the inlet including its chemical components and passively transported organisms which are either not able to resist the water flow or utilize the flow. The tidal inflows of ocean waters to the fiord are observed in its central part most distinctly near the bottom. At the same time, ideal conditions for the vertical mixing of water masses exist. However, the flows exchange of water require more comprehensive investigations.

Water temperature is stabilized by melting blocks of ice floating on the surface, hence, as a rule, it is maintained near 0°C (more

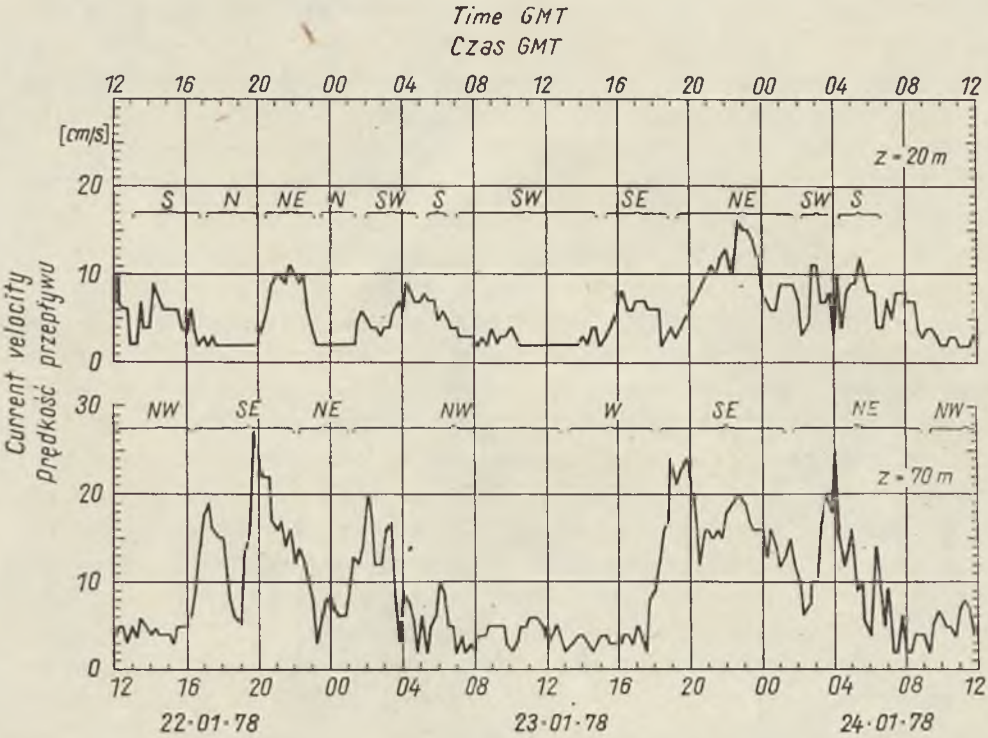


Fig. 3. Part of the record of flows obtained in Ezcurra Inlet at depths of 20 and 70 m at the site positioned between Dufayel Island and southern shore of the fiord (62° 10,38′ S, 58° 32,13′ W; left of the island according to Fig. 1)

Ryc. 3. Fragment wyniku rejestracji przepływów we fiordzie Ezcurra na głębokościach 20 m i 70 m; w miejscu położonym pomiędzy wyspą Dufayel a południowym brzegiem fiordu (62° 10,38′ S, 58° 32,13′ W; z lewej strony wyspy wg zdjęcia na ryc. 1)

exactly between —0.6 to +1.5°C). Vertical temperature gradient is slight and even under extreme conditions in several meters of the surface layer does not exceed 0.1°C/m. (see Fig. 4). During the summer (December 20 to March 10) the gradual increase of the average water temperature by merely 1°C (from 0°C to +1°C near the surface — at a depth of 5 m and from —0.2°C to +0.8°C at 50 m) was observed.

W a t e r   s a l i n i t y shows slight differentiation despite ice confluence and streams from the glacier, thus also indicating a rapid water exchange. The salinity ranges from 33.4‰ to 34.3‰ and diurnal fluctuations as well as vertical differentiation are generally contained in much smaller intervals around the value of 33.9‰ (see Fig. 5). The resulting value of water density written in abbreviated form is about $\sigma_t = 27.3 \pm 0.2$ for the entire water column except specific cases of slightly lower salinity in the surface layer. This obviously facilitates strong vertical

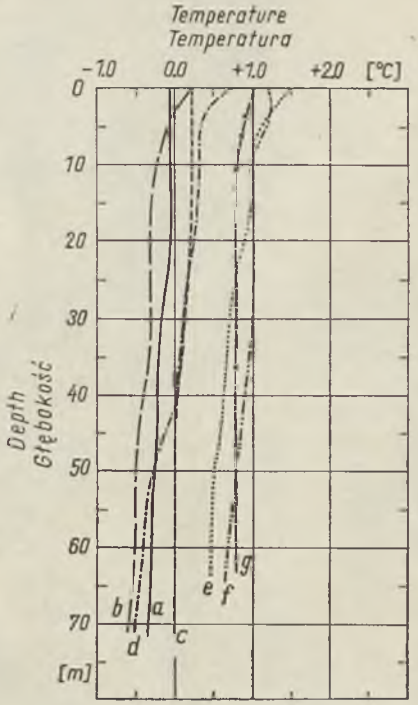


Fig. 4. Vertical distributions of water temperature in Ezcurra Inlet (typical and extreme) for the period of the Antarctic summer 1977/78

a) 12/21/77 06.00 GMT
b) 12/27/77 20.00 GMT
c) 01/04/78 00.00 GMT
d) 01/05/78 21.00 GMT
e) 01/30/78 12.00 GMT
f) 02/14/78 19.00 GMT
g) 03/07/78 16.00 GMT

Ryc. 4. Pionowe rozkłady temperatury wody we fiordzie Ezcurra (typowe i ekstremalne) w okresie antarktycznego lata 1977/78

a) 21.12.77 06 00 GMT
b) 27.12.77 20 00 GMT
c) 04.01.78 00 00 GMT
d) 05.01.78 21 00 GMT
e) 30.01.78 12 00 GMT
f) 14.02.78 19 00 GMT
g) 07.03.78 16 00 GMT

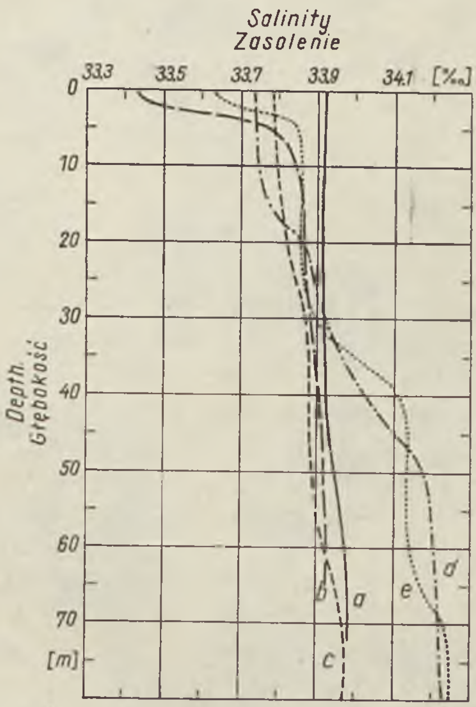


Fig. 5. Vertical distributions of water salinity in Ezcurra Inlet (typical and extreme) for the period of the Antarctic summer 1977/78

a) 12/30/77 12.00 GMT
b) 01/04/78 20.00 GMT
c) 01/21/78 14.00 GMT
d) 01/21/78 21.00 GMT
e) 01/26/78 03.00 GMT

Ryc. 5. Pionowe rozkłady zasolenia wód fiordu Ezcurra (typowe i ekstremalne) w okresie antarktycznego lata 1977/78

a) 30.12.77 12 00 GMT
b) 04.01.78 20 00 GMT
c) 21.01.78 14 00 GMT
d) 21.01.78 21 00 GMT
e) 26.01.78 03 00 GMT

turbulent exchange stimulated by flows and waves. This is indicated by TS diagrams plotted together with the density isolines (Fig. 6). For this reason slight diurnal variations of the majority of parameters are very distinct throughout the entire vertical profile.

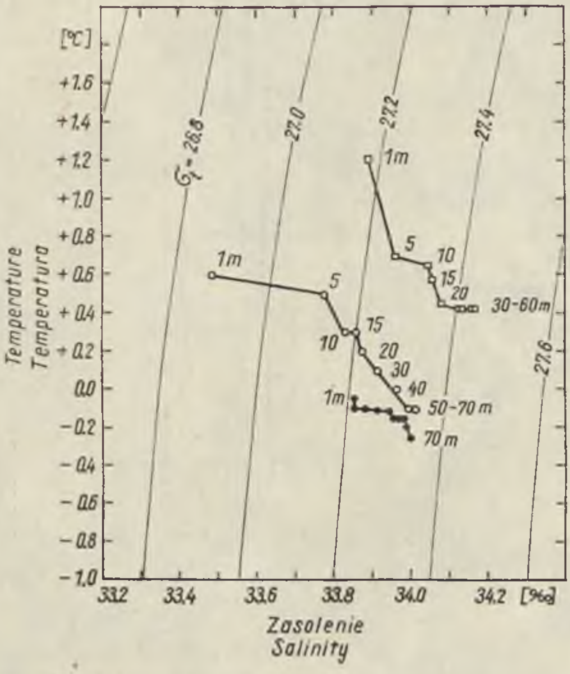


Fig. 6. TS diagrams for the waters of Ezcurra Inlet plotted together with conventional density isolines
○ 01/05/78 ● 12/21/77 □ 01/29/78

Ryc. 6. Diagramy TS dla wód fiordu Ezcurra na tle izolinii gęstości umownej
○ 05.01.78 ● 21.12.1977 □ 29.01.1978

O x y g e n c o n c e n t r a t i o n is high, close to saturation (ca 8 cm^3/dm^3), which has been known for cold Antarctic waters. Maximum variation of the concentration of dissolved oxygen observed during the summer in the whole vertical profile ranged from 6.40 to 8.40 cm^3/dm^3. The average variations in shorter periods of time are much smaller. In summer the variation of oxygen concentration can be successfully approximated by the normal distribution with average values 7.70 cm^3/dm^3 and 7.39 cm^3/dm^3 at depths of 10 m and 50 m, respectively. The respective standard deviations are 0.27 cm^3/dm^3 and 0.38 cm^3/dm^3. At the investigation site greater diurnal variations of oxygen concentration are observed near the bottom rather than the euphotic zone, thus indicating that direct influence of the primary production on this process is of minor importance. A marked depletion of oxygen in the water layer at a depth of 50—60 m was observed during night hours in particular, which may be attributed to the respiration of larger masses (clouds) of zooplankton organisms.

N u t r i e n t s such as silicates, nitrates, nitrites and phosphates exhibit high concentrations which are close to values typical for Antarctic waters south of the convergence zone. This also indicates that the circulation of the inlet waters is common with adjacent open sea, providing a constant supply of these substances to the coastal zone. Average concentrations in the Ezcurra Inlet are as follows: silicates — 80 μg at Si/dm³, nitrites — 0.18 μg at N/dm³, nitrates — 25 μg at N/dm³, phosphates — 1.90 μg at P/dm³. Place- and time-dependent deviations from these values are highest for phosphates (up to 20%), whereas for the remaining they do not generally exceed 5%. These slight variations of concentration show good correlation with salinity variations, the increase of the concentration being coincident with bottom water inflows to the fiord. Vertical distribution of these and other chemical components of the water attain maximum gradients during the still or weak wind periods, while during very strong winds the water at the investigation site becomes practically homogeneous down to the bottom as shown in Fig. 7.

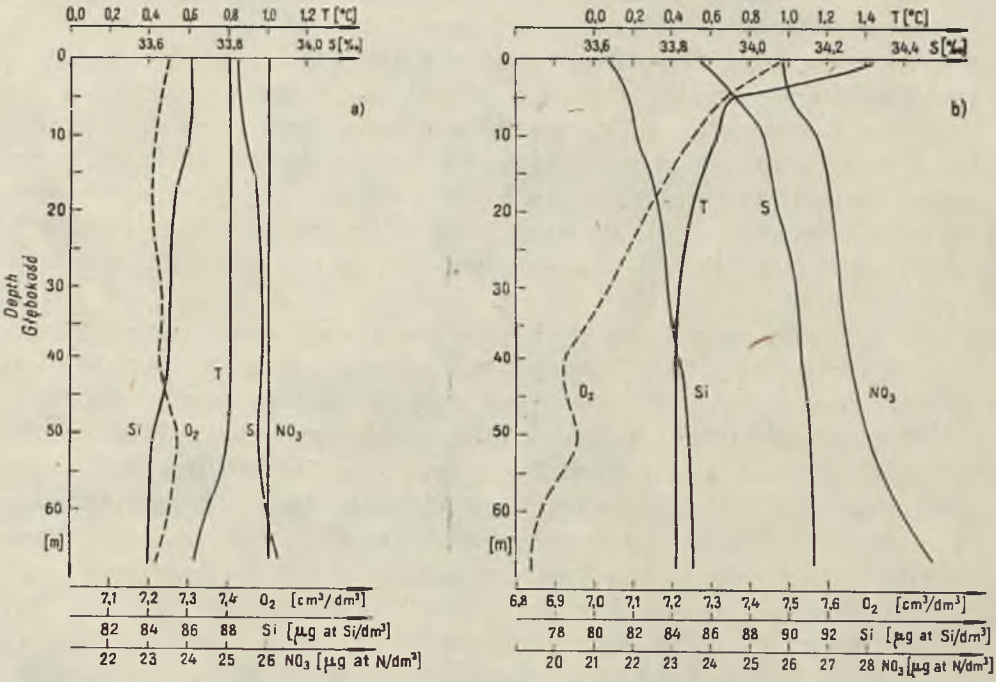


Fig. 7. Comparison of vertical distributions in Ezcurra Inlet for two extreme cases of meteorological conditions:

a) after strong gale 03/07/78

b) during a light breeze 01/29/78

Denotations: T — temperature, S — salinity, O_2 — oxygen concentration, Si — silicon, NO_3 — nitrate

Ryc. 7. Porównanie rozkładów pionowych parametrów stanu wód fiordu Ezcurra w dwóch skrajnie różnych sytuacjach meteorologicznych

a) po silnym sztormie (7.03.1978)

b) w okresie słabych wiatrów (29.01.1978)

Oznaczenia: T — temperatura, S — zasolenie, O_2 — stężenie tlenu, Si — stężenie krzemionki, NO_3 — stężenie azotanów

Due to the high concentrations of nutrients in the fiord waters, as well as their small time- and place-dependent variations, it is difficult to demonstrate a direct effect of biological factors on the concentrations.

Measurements on some water samples taken at random for more detailed analyses indicate that at least 80% of the nitrogen and phosphorus compounds occur in the fiord water in the mineralized form, i.e. as inorganic ions. Further detailed analyses of collected samples will also provide information concerning heavy metals dissolved in water, chemical composition of suspended matter and material washed out from land and glaciers surrounding the inlet.

Suspended matter and water transparency in the fiord depend on the processes of glacier ablation and washing out of the material from the surrounding rocks. Floating ice blocks carrying dust previously deposited on the glacier by wind, as well as rubble, are direct sources of suspended matter. Numerous streams flowing from under the glacier and carrying suspended matter are another source.

Erosion-susceptible rock material in around the inlet consists mainly of lava, breccias and andesite tuffs, whereas andesite and basalt veins visible on steep slopes not covered by the glacier are of secondary importance. All rocks are cut by quartz and ore veins and their surface is very weathered, cracked and detrited as a result of water and frost action.

Due to the presence of such local sources of large amounts of inorganic suspensions, their concentration in water is highly variable and directly dependent on the tide phase and hydrometeorological situation.

The concentration by number of suspended particles with diameters larger than 2 μm (determined by means of a Coulter counter) varies from 7000 to 60000 particles per 1 cm^3 of water, the concentrations near the bottom usually being closer to the lower limit and undergoing less variations with time, generally not exceeding 25 000 particles per 1 cm^3.

The average concentration by number of suspended particles with diameters greater than 2 μm range from 31000 in the upper layer (10 m), through 23000 in the intermediate layer (30 m), to 19000 particles per 1 cm^3 in the bottom layer (50 m and more). The standard deviations are equal to 8600, 6340 and 5350 particles per 1 cm^3, respectively. Similarly to other seas, the size distribution function of suspended matter can be approximated by Junge's distribution: the concentration by number (CN) of the particles with diameters greater than D is given by: $CN = kD^{-m}$, where k and m are constants characteristic for a specific distribution. For the Ezcurra Inlet, the average value of the exponent m is 3.5 and varies very slightly compared to the coefficient k, which reflects the concentration changes. The latter coefficient varies from ca 10^5 to 10^6 cm^{-3}. Good agreement to the size distribution function of suspended particles in the Ezcurra Inlet with Junge's distribution can be attributed to the mechanism of formation of suspensions in the process of rock material desintegration, the contribution of suspensions of biological origin being negligible.

The suspended matter in the Ezcurra Inlet can play an important part in several processes: (1) selective dissolution of suspended matter can influence the chemical composition of the fiord water, (2) relatively large developed surface of suspended particles permits considerable selective adsorption of some components from the sea water, (3) water turbidity brought about by high concentration of suspended particles limits (optically) the euphotic zone and the range of underwater visibility for living organisms.

Water transparency is a good optical indicator of suspended particles concentration and its variation with time. It also determines the range of underwater visibility.

Transparency, i.e. transmission of a beam of parallel rays (radiance transmission, L/L_o) over a distance r = lm can be described by exponential law: $L/L_o = \exp - (a + b) r$ where a and b are the absorption and scattering coefficients, respectively, and their sum $c = a + b$ is the beam attenuation coefficient commonly used for optical characterization of water. In the presence of a considerable amount of large suspended particles of mineral origin, light scattering is a phenomenon determining water transparency for visible radiation. The value of scattering coefficient b, in this case directly dependent on suspension concentration, is therefore very close to that of the attenuation coefficient c. As a result, the variations of the last one closely follow the variations of the concentration of suspended matter and depend in a similar manner on the environmental conditions.

Waters of the Ezcurra Inlet exhibit the highest transparency for green light (ca 525 nm). For this band, at the time of investigation, the most probable values of the beam attenuation coefficient C (525 nm) corresponding to the maximum of statistical distribution were 0.90 m^{-1} and 0.75 m^{-1} at depths of 10 and 50 m, respectively. These values correspond to the most probable water transparency equal to 41⁰/₀/m and 47⁰/₀/m, respectively. However, the probability density distributions of the c (525) coefficient are very flat, extending from 0.3 m^{-1} to 2.4 m^{-1} for the surface layer (5 m) and from 0.1 m^{-1} to 1.3 m^{-1} for the deeper layer (50 m). The average values of c (525) are 1.24 m^{-1} and 0.64 m^{-1} with standard deviations of 0.45 m^{-1} and 0.28 m^{-1}, respectively. Continuous vertical profiles of c (525) recorded in situ usually exhibit considerably higher values near the surface than at a greater depth i.e. large gradients and noticeable edges indicating the water layers of different turbidity can be observed. The latter follow the variations of supension concentrations, which should be evident from the above discussion.

The beam attenuation coefficients c for other wavelengths are higher, e.g. in the violet region generally by 10 to 30%.

Visibility range in water is directly dependent on the light beam attenuation coefficient c and varies considerably in an environment of such variable transparency. As is known, the most probable visibility range in water (contrast of large objects against the water background) can be roughly estimated for average eye sensivity by the ratio 4/c. At depth of 5 m the maximum visibility range slightly exceeds 3 m on average, whereas at 50 m it increases to over 6 m.

Taking into account the observed variations of the attenuation factor c, one can roughly estimate the visibility ranges in the Ezcurra Inlet. Under most favourable conditions they are 13 and 40 m in the surface and deep layers, respectively, although the extremely small ranges of 1.7 m at the surface and 3 m nearer the bottom are twice probable. All intermediate values of the visibility range are more probable than the extreme ones.

It is very likely that these variations of water transparency and thus the visibility influence the distribution and migration of living organisms in water.

Considering the low transparency of water in the Ezcurra Inlet, the euphotic zone range is surprisingly large, basing on an optical criterion. The depth which can be reached by 1% of surface irradiance in the wavelength range corresponding to maximum transmission is 24 m on average, varying with time from 15 to 42 m. It should be recognized that such a thickness of the euphotic zone is extremely large for the transparency observed. This is a consequence of the fact that the in-depth „diffusion" of natural light strongly scattered forward on the suspended particles is, for relatively low absorption, far more effective than the passing of a focused light beam determining the transparency and visibility in the medium. For this reason, the average ratio of the diffuse attenuation coefficient of irradiance K_d (which will be discussed later) to the light attenuation coefficient c is surprisingly low in the waters discussed. The ratio for the upper layer of water is only $K_d(525)/c(525) = 0.16$, which is untypical for a sea of such salinity and depth. In this respect the front of the glacier and the fiord resemble a river mouth — turbid, but not contaminated with organic substances.

Solar radiation in the area of the Ezcurra Inlet should be recognized as very intense, particulary in midsummer (January). The instantaneous values of sea surface irradiance during a sunny day reached even 130 mW/cm^2 at noon, which corresponds to tropical conditions. This value is greater than the one estimated on the basis of the solar constant assuming 100% atmospheric transmission for a given zenithal distanse of the sun. In addition to the known effect of small thickness and high transparency of atmosphere, there are additional local reasons for such high intensity of radiation in this region of the Earth, namely the reflecting properties of the glacier and clouds under favourable conditions. The sky over the fiord, often locally cloudless (due to the above mentioned föhn phenomena), transmits the sunlight directly, and the snow-white slopes of the glacier and surrounding clouds form a perfect screen reflecting the light towards the fiord.

However, dynamic changes in weather bring about strong variations of momentary irradiance values during the day and particularly in a situation when separate clouds, carried by the wind, shield the direct solar radiation continually. Under such conditions the irradiance varies at noon from the values close to 100 mW/cm^2 to ca 20 mW/cm^2, assuming all intermediate values within minutes and even seconds. Minimum irradiance values at noon recorded at full cloud coverage and low cloud level are 13—20 mW/cm^2. All these phenomena undergo diurnal as well as seasonal cycles; it must be noted that nights in the middle of January last only about 5 hours from sunset to sunrise and are light, as opposed to long and dark nights in March.

In this situation the daily irradiance dose, which was automatically recorded during the investigations, was a more convenient parameter than instantaneous irradiance values.

Maximum daily irradiance doses exceed 3000 J/cm^2. The highest value of the daily dose, recorded during the investigation period (January 16, 1978), was 3158 J/cm^2. The day was one of the sunniest days in summer with an average cloudiness of 4.8/8. In the same month (January 5) the minimum value, at full cloud coverage and low cloud level, was 691 J/cm^2. The day-to-day dose of irradiance thus varies by a factor of over 4.

The average daily irradiance dose for January exceeds 2000 J/cm^2 and the typical range is from 1300 to 2500 J/cm^2. In February and March the respective values are lower by several percent due to changes of the sun's position, shortening of the day and worsening of weather conditions.

U n d e r w a t e r l i g h t f i e l d undergoes similar variations with time as solar radiation, additionally enhanced by superposition of the effect of reflections and refractions on the wavy water surface as well as the light absorption and scattering by the medium components. Hence, the variations of underwater irradiance are particularly dynamic due to the influence of the atmosphere on the radiation, as well as winds, waves and concentration of suspended matter in the Ezcurra water.

Transparency of the medium for the radiant power transmitted into water is described by the above mentioned diffuse attenuation coefficient of irradiance K_d, which depends on depth and (to a certain degree) on geometry of irradiance components. The relationship between K_d and the variations of the irradiance E_d in the medium layer dz is given by equation:

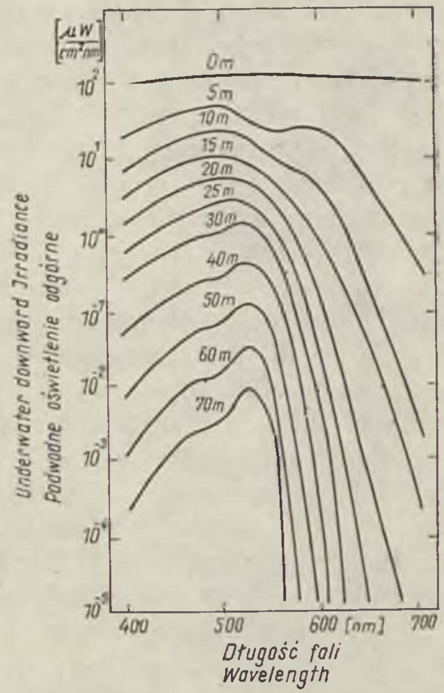
$$\frac{d\ E_d}{dz} = -K_d\ E_d$$

The irradiance attenuation as a function of depth varies with wavelength. In the oceans the attenuation is usually lowest for blue light (460—480 nm). On the other hand in the water of Ezcurra Inlet the lowest attenuation is observed for green light (525 nm). Hence, the diffuse attenuation coefficient of irradiance assumes its lowest values for this band. In the euphotic zone the values cover the range $0.11\ m^{-1} < K_d\ (525) < 0.30\ m^{-1}$. For the entire investigation period the average value in the euphotic zone was $K_d\ (525) = 0.20\ m^{-1}$ with a standard deviation of $0.04\ m^{-1}$. This value corresponds to an average downward irradiance transmission equal to 82%/m in the band for which the Ezcurra Inlet waters are most transparent. The irradiance attenuation coefficients in other spectral regions are higher. For violet (425 nm) and red (600 nm) light the values are higher by 40 and over 70%, respectively. For longer wavelengths, the values increase strongly with wavelength due to the absorption properties of water.

The observed values of K_d(525) coefficient (from $0.11\ m^{-1}$ to $0.30\ m^{-1}$) permit the Ezcurra Inlet water to be included among types from III of ocean water to 5 of coastal water according to Jerlov's optical classification. Strictly speaking, however, in the types of water mentioned above, the increasing turbidity is usually paralleled by the increase of concentration of organic components (absorption in violet) which is almost unobserved in the Ezcurra Inlet.

The resulting underwater light energy at various depths of the fiord waters is a consequence of the solar radiation, the effect of light reflection from the surface (several percent) and the irradiance attenuation as a function of depth. On the basis of random, as yet, analyses, carried out at noon on an average summer's day, when total maximum irradiance of sea surface was ca 90 mW/cm^2, we found the following depth ranges of isaphotes: 10 mW/cm^2 — slightly below 4 m; 5 mW/cm^2 — to ca 8 m; 1 mW/cm^2 — to 18 m; 0.1 mW/cm^2 — to 33 m, 0.01 mW/cm^2 — to 50 m; and 0.001 mW/cm^2 — to 66 m. The average spectral distributions of irradiance at various depths are illustrated in Fig. 8. It should be noted, however, that momentary irradiance is strongly modified by the changes in the atmosphere, water and sun position mentioned above. For this reason it is necessary to take into account the momentary values of irradiance, measured simultaneously with other parameters, in order to correlate the radiant power with other processes occurring in the environment correctly, e.g. photosynthesis rate or vertical migration of zooplankton. Many such correlations can

Fig. 8. Spectral distribution of irradiance in Ezcurra Inlet at various depths — average values for a day in January (01/ /15/78, 11.00 GMT)



Ryc. 8. Spektralne rozkłady oświetlenia we fiordzie Ezcurra na różnych głębokościach — przeciętne w ciągu dnia w styczniu (15.07.78, 11 00 GMT)

be found on the basis of comprehensive data obtained during the expedition.

Underwater light flashes are one of the manifestations of the effect of water surface oscillation on the underwater lightfield. They are strong, short-term local increases of underwater irradiance, resulting from the focusing of sunrays by the crests of waves. The maximum intensities of these flashes exceed the average intensity of irradiance at the investigation site by a factor of 5. Such strong increases of irradiance can influence the elements of the biosphere and accelerate the photochemical reactions. However, in the Ezcurra Inlet, the rate of occurrence and the extent of this phenomenon are limited by (1) high turbidity of the water, (2) frequent strong winds disturbing the water surface to an extent leading to strong light scattering, and (3) short periods of sunny weather in the fiord.

However, in sunny weather and with a wind speed below 10 m/s, rapid flashes exceeding three, four-fold the intensity of direct solar irradiance are observed in the subsurface layer (1—2 m). They depend directly, although in a complex manner, on the spectrum of water surface oscillations, and indirectly on the wind speed, while either during a still (wind speed 0) or during strong winds (over 15 m/s) the phenomenon disappears. Under favourable conditions and wind speed equal to 3.5 m/s, the frequencies of flashes observed at a depth of 1 m were as follows: 30 per minute, 3 per minute, and 1 per 10 minutes for flashes exceeding the average irradiance by a factor of two, three and five, respectively. These and all intermediate flash frequencies decrease exponentially with an increase of their intensity. For other wind speeds the flash frequencies observed are lower. Duration times of flashes exceeding the average light intensity by 150% are short, of the order of milliseconds. The probability density distribution of the times exhibits a maximum in the range of 20—30 ms and is strongly extended towards long times (up to 150 ms). The second maximum appears for waves of complex spectrum. The average duration times of flashes are generally close to 30—40 ms for gentle winds and considerably longer, i.e. 70—80 ms for the strong ones (10—12 m/s). This phenomenon is extremely susceptible to numerous external factors modifying the dynamic state of the water surface and the degree of light scattering.

Phytoplankton in the Ezcurra Inlet waters, at present analyzed in a few of the collected series of samples, contains diatomeae and green Flagellata, the former dominating in December and the latter in January, February and March. Among the diatomeae, algae of the genera: Corethron, Coscinodiscus, Chaetoceros, Fragilariopsis, Rhizosolenia, and Thalassiosira prevailed. The class of Flagellata was represented mainly by small cells (5—17 μm) resembling Chlamydomonas. One may generally assume that quantitative and species variations are small. The values of concentrations of all cells ranged usually from 10 to 200 in 1 cm^3 of water, taking into account both variations with time, as well as depth in the euphotic zone.

Pigment concentration studied in water samples containing phytoplankton undergo considerable variations with time and sampling site, this being the effect of variations of both the primary production as well as flows and vertical mixing of waters.

Chlorophyll **a** was usually observed at concentrations varying from 0.5 to 1.5 mg/m^3 (at the beginning of December twice as high!), chlorophyll **b** — generally below 0.05 mg/m^3, and carotenes — from 0.2 to 0.8 mg/m^3. The vertical distributions of these pigments frequently exhibited tendencies to a slight maximum (on the order of 10% or more of increase) at the intermediate depths, i.e. nearer the lover boundary of the euphotic zone and a decrease of concentration even to half the maximum value near the bottom. Other situations also exist, when the pigment concentration is uniform or maximum near the bottom, which proves the hypothesis concerning the exchange of water together with its contents.

The primary production depends either indirectly or directly on all the factors mentioned as well as on others. The chemical components present in water, underwater lightfield, currents and vertical exchange of water exert a particularly strong influence. There are sufficient amounts of nutrients and microelements in these waters, which facilitate the primary production. Light intensity in summer is moderate due to water turbidity. On the other hand, the primary production may be inhibited by water movement transporting the cells to deeper regions more rapidly than their photoadaptational ability, even partially beyond the euphotic zone.

The random samples analyzed so far indicate an average rate of production in the water layer from 0 down to 30 m equal to 1.27 mg C/ /mg chl. „a" • h, and average production in the water column equal to 700 mg C/m^2 • day. The value of primary production most frequently observed during the investigations in the Ezcurra Inlet ranged from 400 to 900 mg C/m^2 • day. The maximum value (observed on January 17, 1978) was 1360 mg C/m^2 • day, whereas the minimum one (March 10, 1978) was 150 mg C/m^2 • day. The above values of primary production are comparable, e.g. with the production in the Baltic. The detailed analysis of collected data will enable the determination of photosynthetic efficiency and the effects of pigments in this process.

As observed, zooplankton in the Ezcurra Inlet occurred in the following forms of halo- and meroplankton during the summer of 1977/78: Siphonophora, Polychaeta, Nematoda, Mollusca, Crustacea, Echinodermata, Chaetognatha and Apendicullaria. The most numerous groups among the plankton animals were Crustacea, especially Calanoida and Cyclopoida (Eutomostraca), as well as Euphausiacea (Malacostraca). The presence of vertical diurnal migrations of zooplankton was observed and random analyses of some of the samples collected indicate the variations in domination of various animal groups of haloplankton during the season mentioned.

Bioluminescence of a number of zooplankton species occurring in the fiord permits the investigation of their presence and certain reactions under specific conditions by means of a sensitive photometer. The depth at the anchorage was insufficient for the „in situ" investigation of natural bioluminescence. Therefore, these observations were carried out on freshly collected samples of zooplankton „in vivo". Samples containing substantial amounts of bioluminescence-exhibiting zooplankton (from 100 to 300 representatives of Metridia, a dozen of Euphasia and others in a water column from 0 down to 70 m for net diameter of ca 60 cm and mesh size 250 μm) were collected at this depth almost exclusively at night, thus indicating their diurnal migration.

As a rule, freshly collected samples exhibited intense bioluminescence in a form of frequent light pulses (Fig. 9). Intensity of these pulses for several minutes after collection of a sample (after the shock associated with being taken out of sea and placed in a 1 dm^3 measuring cuvette filled with sea water maintained at 0°C in darkness) is of the order of 10^{-6} μW/cm^2 • nm of irradiance at a distance of 20 cm in the investigated wavelength band of 480 nm. The intensity decreases with

Fig. 9. Bioluminescence pulses of an average sample of zooplankton from the Ezcurra Inlet waters for the period of the Antarctic summer 1977/78

T — time, E — intensity of bioluminescence in the 480 nm band.
The time scale for successive rows of the record increases upwards (from T_0 to T_5).
Units are marked by arrows on the diagram $6.2 \cdot 10^{-9}$ $\mu W/cm^2$ nm; 10s

Ryc. 9. Impulsy bioluminescencyjne przeciętnej próby zooplanktonu z wód fiordu Ezcurra w czasie antarktycznego lata 1977/78

T — czas, E — natężenie bioluminescencji w paśmie 480 nm
Jednostki skali oznaczono strzałkami na wykresie.
Kolejne wiersze zapisu następują w czasie po sobie z dołu ku górze wykresu.

time and, after 1 to 3 h is lower by ca 3 orders of magnitude. At the same time, the average number of pulses is reduced from ca 100 per minute in the first few minutes to ca 1 per minute and less after about 2 hours. Among the recorded pulses, decisively predominating ones were regular sharp peaks with rise time below 0.5 s and relaxation time of the order of 1 s, which were experimentally attributed to Metridia. Certain differentiation of relaxation times was clearly observed. It is possible that this phenomenon can be ascribed to the occurrence of various species of Metridia (Metridia longa, Metridia gerlacheii), although other explanations are also possible. On the other hand, the same representatives of Metridia are capable of emitting pulses varying in intensity by 3 to 4 orders of magnitude.

It was found that the most intense light pulses were generally associated with shock brought about by an external factor, whereas the intermediate ones seemed to be connected with the coexistence in unmatured conditions of various species of zooplankton in a small living space.

An isolated collection of Metridia left undisturbed for several hours exhibited very weak bioluminescence, i.e. emission of light pulses of various intensity with an average frequency of 1 per hour per representative of the species. However, deviations from this value are considerable, thus indicating the necessity for further investigations. Although the biochemical nature of bioluminescence is known, the behaviour of many species of zooplankton in this respect remains speculative. Our observations of several dozen collections of zooplankton from the Ezcurra Inlet suggest that electromagnetic waves (visible) emitted by investigated microorganisms are a certain equivalent of acoustic waves (sounds) emitted by other animals, e.g. squeaking, cackling, howling and roaring, or signals communicating and expressing emotional states in moments of emergency characteristic of a given species. An obvious example of a reaction caused by terror is intense luminescence of many species of zooplankton immediately after their being taken from the water, or caused by mechanical shock (e.g. by the side of a moving ship). This phenomenon can generally be noticed with the naked eye. Similar and other manifestations of activity of these organisms are observed on complex bioluminescence recordings.

In the samples of plankton from the Ezcurra Inlet, in addition to very characteristic sharp peaks of spontaneous bioluminescence of Metridia, a certain number of other light pulses is observed. These we could not attribute to luminescence of definite species with the exception of Euphausia superba (identified with the aid of chemical stimulation: NH_4OH). As a result of chemical stimulation the luminescence of Euphausia reached an intensity of ca 10^{-5} $\mu W/cm^2 \cdot nm$ (irradiance at a distance of 20 cm). The luminescence is very irregular, exhibiting a long time of „switching on", long period of glow (ca 1 minute) with occasional intense scintillations. This is due to the lighting up of individual photophores controlled by nervous system of Euphausia, as well as to the regulation of the intensity and direction of light. The nature of the luminescence of Euphausia is known to be different from that of Metridia but the role of this phenomenon may be similar. The identification of the luminescence of numerous other species present in the samples of zooplankton from the Ezcurra Inlet seems to be posible in further investigations due to the characteristic shapes of recorded bioluminescence pulses.

It should be pointed out that the sensitivity of visual organs of the above mentioned species of zooplankton is considerable since they are able to receive light signals with an intensity 10 orders of magnitude lower than that of daylight at the sea surface. This fact facilitates their existence during the polar winter and explains their escape into deeper waters during the day (diurnal vertical migration) as well as the „light shock" they undergo after being removed from the sea depth to daylight. One can assume that bright daylight leads to the damage of photosensitive organs of these organisms. Similar visual sensations can be felt by some species of abyssal organisms as a result of light flashes emitted towards them by other organisms.

3. CONCLUSIONS

The conclusions will be restricted to a few statements not arising directly from the above description of the fiord, or being otherwise important for future investigations.

The natural processes in coastal Antarctic waters are more directly than anywhere dependent on the interaction of the sea, atmosphere and the sea coast with its icing typical for polar regions. This interaction can be distinctly observed in the Ezcurra Inlet and its surroundings, which is an ideal model „miniaturized" by nature to a size enabling to detailed investigations. At the same time, this region forms one of the links of mass and energy exchange on the southern, cold side of the Antarctic convergence zone. Thus, comprehensive investigations of natural processes in this region are of more general importance than the local ones. They result in the recognition of very complex mechanisms of the formation of weather, climate, energy flows, circulation of substances in nature, equilibrium in sea ecosystems and others. These processes are of vital importance for life on Earth and they require further investigations in this not easy accessible part of Earth. This suggests the necessity for further well prepared comprehensive investigations in the field of meteorology, oceanology, hydrobiology and other Earth sciences during future Antarctic expeditions. However, the effectiveness of these investigations will be determined by their comprehensiveness, since dynamically variable processes in the atmo-, hydro- and biosephere do not respect interdisciplinary boundaries, an example of this being the phenomena described in the present paper. For this reason, these investigations more than others require international co-operation.

The situating of „Henryk Arctowski" polar station on the small strip of territory of King George Island, surrounded by ocean, in a place particularly important for investigations also requires that more attention be paid to the adjoining ocean and atmosphere in its research program.

Original materials for this elaboration were data obtained during the 2nd Antarctic Expedition of PAS, and particularly by an oceanographic and biological research group, namely:

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OCEANOGRAFICZNE ROZPOZNANIE FIORDU EZCURRA PODCZAS II WYPRAWY ANTARKTYCZNEJ PAN *

Streszczenie

Scharakteryzowano zjawiska przyrodnicze we fiordzie Ezcurra na wyspie King George na podstawie wstępnej analizy wyników badań II Wyprawy Antarktycznej PAN w czasie antarktycznego lata 1977/78. Uwzględniono warunki meteorologiczne, elementy hydrodynamiki, spływ lodu, temperatury, zasolenia i natlenienie wód, substancje biogenne, zawiesiny i przezroczystość wód, promieniowanie słoneczne i podwodne pole światła, pigmenty, fitoplankton i produkcję pierwotną oraz zooplankton i jego bioluminescencję. Badania te wykonane zostały przez zespół naukowy wymieniony na końcu opracowania. Opracowanie w języku polskim zamieszczono w „Studiach i Materiałach Oceanologicznych" nr 25.

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