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ON THE TERRESTRIAL FAUNA OF THE ROSS-SEA AREA, ANTARCTICA
(Preliminary report)

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Working on the United States Antarctic Research Program (USARP) of the National Science Foundation in connection with the Bishop Museum project, in the southern summer 1961/62, I studied the terrestrial animal communities and their environmental relations in the area of the U. S. McMurdo Station (Ross I.), within the limits of accessibility by helicopters. The southernmost point reached in field work was the Plunket Point region at the head of the Beardmore Glacier, where elevations up to 3330 m were investigated (Anna Heights[1]) north of Mt. Nimrod, approximately 85°15′ S, 167° E. In this Plunket Point area, we could not find any sign of life[2] (see also fig. 2).

Samples were taken especially in South Victoria Land from the coast to the innermost mountains adjacent to the ice cap to the west, roughly between Mackay Glacier in the north and Ferrar Glacier in the south (77°1′ S to 77°56′ S). We investigated at elevations up to about 2200 m, also in some places in the neighborhood of McMurdo (Dailey Is.; Cape Crozier, Cape Royds, etc.), and on Mt. Erebus, the only active volcano of Antarctica, up to its top (4040±20 m). We spent about two months sampling the area and living in a tent. I was partly assisted by Keith A. J. Wise (Bishop Museum), and always in company with the pedologist Dr. Fiorenzo Ugolini (Rutgers University) who also was my good comrade on the ascent of Mt. Erebus (where on the descent we had a bad time with the crevassed areas under whiteout conditions). I also appreciated very much our pedological discussion.

Measurements of microclimatic factors were made whenever possible in the camp sites, sometimes covering the whole range of 24 hours. The results are still in elaboration as well as the processing of the data on the population densities of the observed ecosystems and the determination of the collected materials.

Two terrestrial ecosytems (and biocoenosis as their biotic part respectively) can be distinguished in the visited area of Antarctica: a) the "Chalikosystem" and b) the "Bryo-system."

1. Preliminary name for the unnamed area of table mountains north of Mt Nimrod, first visited by Dr. F. Ugolini (Rutgers University) and myself.
2. Including microphytes as also shown by the results of the microbiologist of this expedition, Dr. George H. Meyer (University of Texas), per oral communication.

a) The system of naked rubble as weathering products of bedrock and/or moraine of different age without visible (macrophytic) vegetation can be called "Chalikosystem." It is inhabited by a hemiedaphic mesofauna: 3 or 4 species of Collembola and 1 or 2 species of mites (Oribatids have not been found here; they seem to be absent in both ecosystems of the area). By reason of methodic difficulties, the possibly present microfaunal part of this Chalikosystem (not visible with hand lens) has not yet been investigated. The very short and simple food chain for the mesofauna apparently begins with the utilization of soil-fungi by Collembola; soil microphytes seem to be present in all the places without any visible vegetation whenever inhabited by arthropods, almost as high as 2000 m, corresponding to the upper limit of vertical distribution of the Chalikosystem[3]. Our relative statements on the mountain crests at the head of Mackay Glacier could be near the absolute limits for terrestrial animal life in those southerly latitudes under normal environmental conditions. (Concerning possible exceptions see later). At these elevations near or at the upper limit of its distribution, this Chalikosystem is represented as to fauna by a very impoverished facies, consisting of 1–2 species of springtails only. The species in question are not yet determined and may not be described. In contrast to the later mentioned temperature range of the abundant coastal form, they are relatively rare, still active at lower temperatures and probably cold-stenothermic. As Collembola and the other members of this system, all soft-skinned forms, are relatively more hygrophilous, the most important and really limiting ecologic factor for these first pioneers of terrestrial animal life is not the temperature of the soil, but its moisture content. Besides many other influencing factors, the humidity of the soil air and the surface is closely correlated with the contents of the soil on clay and therefore to the petrography of the underlying bedrocks or of bedrocks more or less far away as the source of clay-forming minerals; transported for instance in moraines.

b) The system of more or less open, rarely closed macrophytic vegetation composed by some mosses, lichens and more exceptionally, thin algal covers can be called "Bryosystem" since coenologically mosses play the most important role. The dominants of the zoocoenosis belong to the microfauna; the too little investigated Protozoa, some nematodes, bdelloid rotifers and tardigrades. Therefore, concerning "life-forms", the components of the antarctic bryofauna are the same as in the other parts of the world with analogous ecological attributes, and may even be specific identities. Concerning this and the possibility of some faunistic relations to antarctic ponds, one has to await the results of the respective determinations. The vertical distribution of the Bryosystem is correlated with the upper limit of scattered growth of mosses and soil lichens respectively. In the investigated area this is at least up to about 1300 m (top crests of Mt. Suess and Mt. England). Ecologically more pretentious, this system follows behind the Chalikosystem in the ecologic series. Under the climatic and pedologic conditions of the McMurdo area, it is simultaneously its climax stage as the end of possible development of terrestrial communities in this extreme environment.

Actually, in many places, both systems occur one beside and amid the other, as a mosaic, corresponding to the change of conditions in nearby spots in the same place. Ceteris

3. Hyphae of fungi seen at 2000 m and *Aspergillus* cultivated from bare gravels from the measuring site at the northern slopes of Skew Peak, 1880 m (cult. & det. Dr. E. D. Rudolph, Ohio State University).

paribus the latter seems to be caused primarily by the microrelief with its direct influence on vectorial environment factors like insulation and wind; indirect influences of others, like temperature, snow, snowborne humidity, etc.; and all together, forming the warmth and water content in the actual ecotope.

The absolute highest plant and animal life was found at 3600 m on the western facing slopes of Mt. Erebus in soil of the extended region of fumaroles between the active crater and the next older one below. This soil had a pH of 4.2–4.3 and contained microorganisms only: mixed populations of fungi and bacteria (none *Actinomyces*)[4]; Cyanophyta (about 3 genera); rhizopod Protozoa; a very small and colorless species of bdelloid rotifer; and perhaps also tardigrades, of which I found only an old cyst. The top of Mt. Erebus itself (this means the ridge of the active crater at a bit higher than 4000 m), where the soil has a pH of 2.7–2.8, is completely sterile. Certainly the occurrence of life at this extremely high altitude in Antarctica is exceptional and is caused by the volcanically raised soil temperatures and constant moisture supply.

The last week of my stay at McMurdo, when field trips were no longer possible, was used for experiments on the temperature range of the springtail ***Gomphiocephalus hodgsoni***, the common form of the coastal area of McMurdo Sound. The results are schematically represented in fig. 1.

Surprisingly enough its temperature preference (T. P.) is $+11.32 \pm 0.55$°C (statistic middle $M \pm 3m$ of 153 readings). The highest beginning of reversible cold stupor was observed at $+6.5°$; Anabiosis, with complete cessation also of the slightest microscopically visible movements, began at $-18°$. The proved frost resistance reaches to $-20 \pm 2°$; lower temperatures, as $-28°$, are lethal. The lowest commencement of temporary (reversible) heat stupor was seen at about $+20$°C, but already at $+17.5°$ the region of supraoptimal activity begins, in which the normal feeding seems no longer possible. Death by heat was caused by temperatures above $+33°$. There are phobic reactions against heat. Thermoreceptor sense organs are very probably on the antenna, judging from the behavior of the animals. Against the cold, similar protective mechanisms probably do not exist. The result of this kind of equipment with sense organs can explain the asymmetric shape of the frequency curve (see fig. 1). Depending on a complex of factors the ranges of normal and disturbed activities and reversible stupor more or less overlap. There are some indications that the individual possibility of lowering the temperature grade at which cold stupor begins as well as the change of the combination recovery-time to recovery-temperature in reactivation from the cold stupor in ascending environment temperature, maintains a certain correlation to the velocities of the respective change of surrounding temperatures. The analyses from the standpoint of mathematics and physics are still in progress and the possible biological constants of the species are not yet comprehended. But the existence of an ecologically optimal range of $\pm$temperature gradients seems probable. This would mean that besides the hitherto considered maxima, minima, averages, and sums of habitat temperatures, the changes of $\pm$ gradients are also of ecologic importance and should be studied.

The above mentioned high level of the temperature preference and the position of the range of undisturbed activity are surprising as being found for one of the southernmost

4. Oral communication by Dr. Starkey, Rutgers Univ., New Brunswick, who has investigated for bacteria, fungi and pH samples which F. Ugolini brought back into the States.

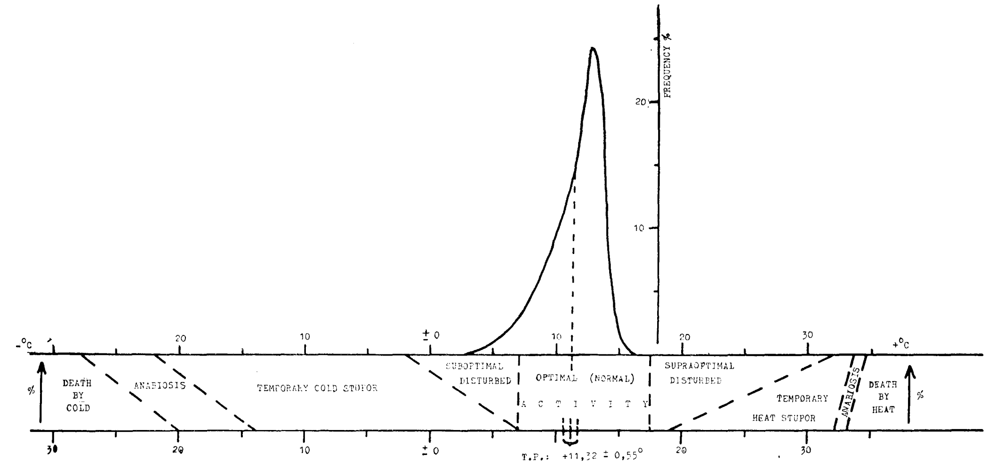

Fig. 1. Temperature range of the springtail *Gomphiocephalus hodgsoni* from the McMurdo Area (Antarctica). Schema on the base of my experiments. The horizontal stripe shows the estimated limits of resistance and tolerance. The frequency curve as simplified result of experiments on the temperature preference (T. P.) is set over the appertaining temperature range.

known terrestrial animals of the world. The species seems not to be in harmony with and not peculiarly adapted to the severe climate of Antarctica and rather to be a stranger from the ecological point of view. It perhaps immigrated in relatively recent times from subantarctic islands situated to the north in the same range of longitude. This assumption of relatively young age of the antarctic populations of this species could explain best why it has been hitherto impossible to find any in a number of biotopes in the same area. That is, biotopes with similar life conditions as in the occupied ones. The ecologic niche for *G. hodgsoni* would exist but would not be filled in places like the Dailey Islands (only 1 visited) or the area of McMurdo itself (Hut Point Peninsula) by reason of the time factor. There has not yet been enough time for the accidental establishment of populations by air transport from places already occupied.

On the other hand, the range of activity found by laboratory experiments is in sufficient agreement with the microclimatic conditions in the natural habitat (of which fig. 2 gives one example only) for during many of the 24 hours of the cycle some soil temperatures are high enough to permit feeding and reproduction. The readings at Cape Crozier, the example represented in fig. 2, are by no means the highest ones. By reason of the limited range of readability of the available instrument, it was not possible to get an exact possible maximum temperature; but readings with sand-covered Hg-Thermometers sometimes gave $+20^{\circ}$ and certainly the temperature on surfaces of soil, stones and rocks can increase still more, therefore reaching sometimes grades even dangerous for the species. But those sandy spots which can become too hot, I found were avoided by the arthropods and to be practically sterile. This, of course, could also be caused by the concomitantly decreasing humidity. As already mentioned, in most localities humidity seems to be the minimum factor and therefore the limiting one, as it is for most of the so called "Dry valleys" region. Under the investigated points, Cape Crozier had the richest life (concerning numbers of individuals, not numbers of species). For instance, I counted about 1000 soil rotifers

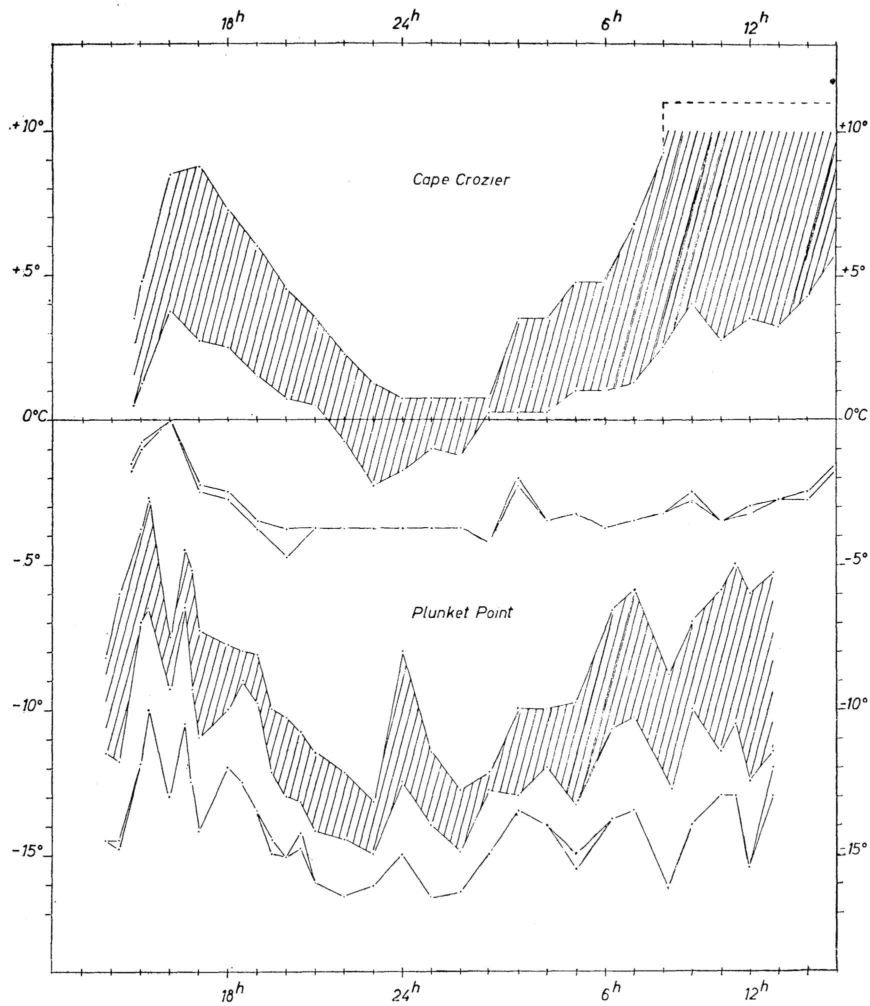

Fig. 2. Diagrammatic representation of two examples of microclimatic tempera ture differences in the Ross Sea Area (Antarctica). A. Upper part: Measuring site at Cape Crozier (Ross I.), approx. 77°30′S, 169°40′E; 128 m, inclination about 2°, northerly; 20. XII. 14:45–21. XII. 15:00, 1961. Weather during the readings: clouding mostly 10/10, some snowing, light winds. B. Lower part: Measuring site at the Plunket Point Area on the head of the Beardmore Glacier, approx. 85°05′S, 167°E; 2650 m, inclination about 1°, northerly; the heavy winds from the adjacent South Polar Plateau are diminished by the sheltering effect of a dam of "young" moraines south of the measuring site; 5. XII. 13:50–6. XII. 12:50, 1961. Weather: mostly sun, high cirrus 3/10–9/10; strong winds. Explanation of signs: ——— = air temperature 1 m above ground. The sometimes occurring quick fluctuations are schematically represented. ////////// = temperature range between the extremes of 5 (A) and 3 (B) comparably fixed measuring points on the upper and underside of stones (in B: plate of Beacon sandstone 0.5 cm thick; in A: basalt pieces 1.8 cm), and in the uppermost parts of the soil (fine gravels) about 0.5 cm deep. The dashed continuations (- - -) in A, right, are above the range of the available instrument, and higher than +10° C. Depending from the conditions of the incoming solar radiation they very probably can mount at least to +20°C and more. Concerning the life under those different conditions (A and B) see text.

in 2 cm^2 of a thin cover of soil algae (*Prasiola*). This would mean about 5 million per square meter (the whole *Prasiola*-spot covered more than 2 m^2). Those and analogous population densities of terrestrial animals are only possible by favorable combinations of many factors, among them humidity, as the "first condition for life" (Thienemann). But it would be a mistake to draw conclusions on productivity from those numbers. The actual production of terrestrial animals is certainly not higher than in the approximate size of up to maximal some hundred milligrams per liter soil only and comparable with the very scanty production of pioneer phases in the development of animal populations in primary soils very poor in humus on higher mountains in temperate zones.

Ecologically very important also is the stability or instability of the environmental conditions. Among the points for the measuring of microclimate in the Chalikosystem, the fine gravelly and sandy soil near the surface showed the highest eustasy, the best microclimatic buffering, and represents therefore the optimal ecotope. Surprisingly, thin snow patches as remains of the winter snow cover do not give protection in the summer, but make living conditions worse by undercooling the environment at its edges. The delivery of moisture by those snow patches seems to be of little importance since they rarely melt to water but evaporate directly in the dry air. Therefore the most stable humidity supply is given by the already mentioned contents of the soil on clay. Under these circumstances the deeper going of the relatively high permafrost level by the influence of higher temperatures, which also enables animal activity, provides constant humidity supply. The absence of visible life in many localities thermically more favorable than those where animals were found, can almost be explained in certain cases by the absence of clay. In addition, a historical factor may be important: the chance to survive earlier, wider glaciations on suitable localities. Distribution and abundance of certain springtails along profiles from the coast to the mountains of South Victoria Land adjacent to the inner ice cap suggest two species of Collembola to be autochthonous (native) in this area, since the times of their speciation. They belong to the more impoverished facies of the Chalikosystem developed under more extreme conditions. Therefore the Chalikosystem seems to be not only the first pioneer of life as a successional stage but also the oldest in South Victoria Land.

On the other hand, on Mt. Suess, rock-lichens were found to have completely covered, and closed rock surfaces of more than 4 m^2. As only a low percent of these lichens were still alive, the conclusion may be drawn that in this area there existed earlier, warmer and more humid periods after the retreat of the ice cap from the coastal part.

Processes of soil development in the discerned ecosystems usually only reach a poor "primary soil" with very little contents of "primary humus"[5] in the Chalikosystem, but on locally favored places (with or without influence of birds)[6] they can reach a stage like a kind of "Protoranker" and "Ranker"[5] in the Bryosystem.

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5. Using the terminology of *Kubiëna* which is developed in regard to the biotic influence on soil development and the associated kinds of humus; see *W. L. Kubiëna*, Entwicklungslehre des Bodens, Springer, Wien 1948.
6. The influence of birds on development of biocoenoses and soils seems to be of relatively little general importance and rather limited to a comparatively small area in the neighborhood and in the background of penguin rookeries and skua territories. In the rookeries themselves the influence is absolutely negative; every development is stopped. On the other hand birds certainly can be responsible for the passive dispersal of some animals especially members of the bryofauna.

Putting together both pedologic and coenologic characteristics of the discerned systems from the worst to the best conditions gives the following schematic arrangement:

Chalikosystem ⟶ mosaic of both ⟶ Bryosystem
(primary soils ⟶ "Protoranker" ⟶ "Ranker")

The best development of the first, considering numbers of individuals as well as of species, I saw on Mt. Suess at altitudes of about 1000 ± 200 m; the best of the last on the right young moraines of the Blue Glacier near the outlet at the coast, at 60 m. There are more or less closed stocks of mosses with an extent of about 50 or 60 square meters.

Both systems may reach almost till about 86°S in the Queen-Maud-Range area in the innermost corner of the Ross Sea; the exploration of the mountains along the Scott Glacier especially is to recommend for future expeditions. The vertical distribution could reach up to about 3000 m in the northern coastal ranges of the continent, since already the 4th Russian Antarctic expedition found mosses and lichens in 2700 m in the region of the USSR station Lazarev in Queen-Maud-Land in 71–72°S.

I have to thank the Bishop Museum, Honolulu, particularly Dr. J. L. Gressitt, and the USARP of the National Science Foundation, who made possible these investigations; the staffs of the organization "Deep Freeze" and of the USARP, for the logistic support; and my companions on the field trips for their good comradeship and help.

NOTE: The final report on this field work will be dedicated to Prof. Dr. O. Steinböck on the occasion of his 70th birthday.

RECENT LITERATURE ON PACIFIC INSECTS

Diptera

(Continued from page 280)

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