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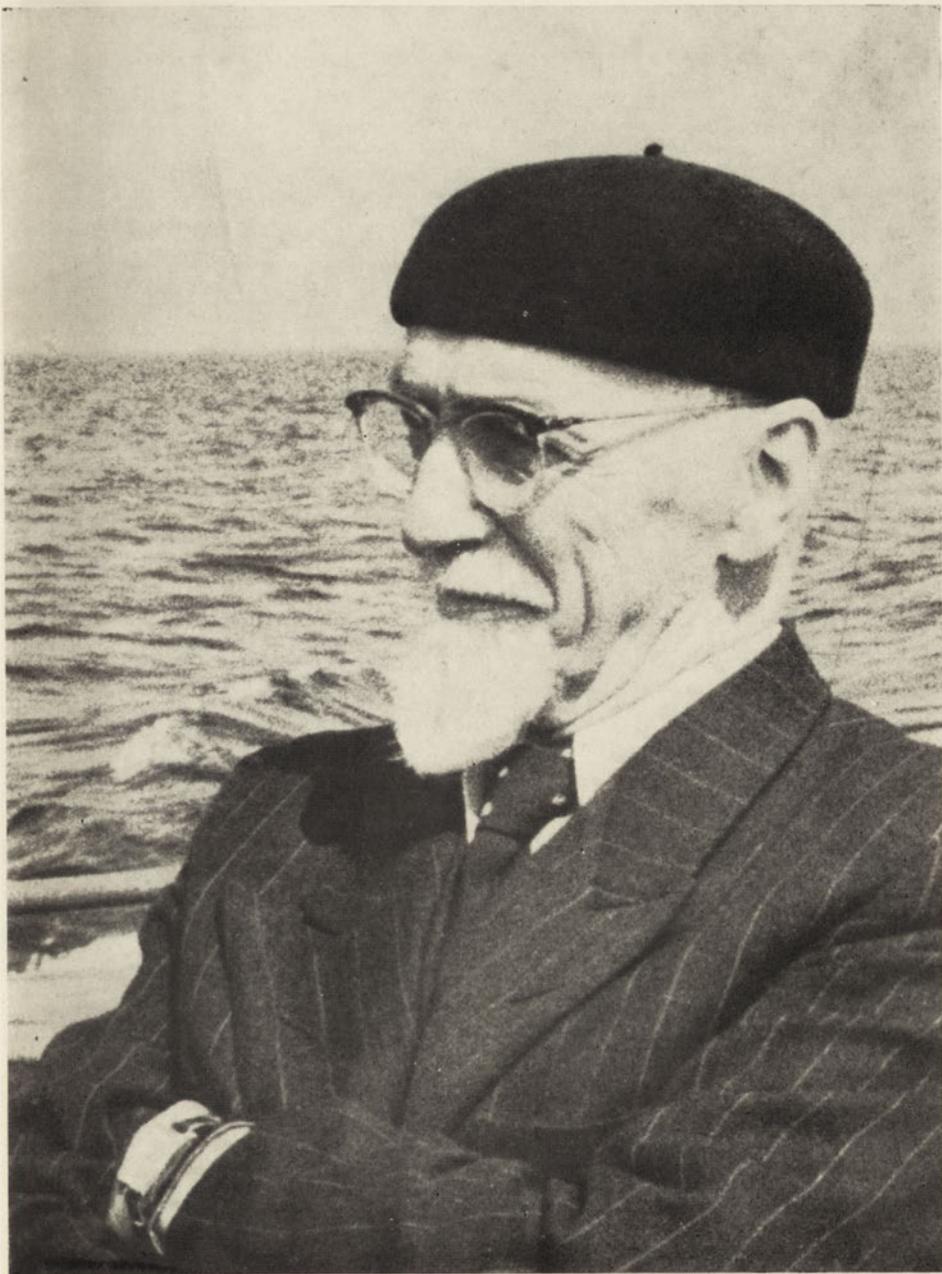
Prof. dr Mieczysław Bogucki

PROFESSOR Dr. MIECZYSŁAW BOGUCKI

On 8th February 1965 died one of our most senior Polish hydrobiologists, Professor Mieczysław Bogucki. Polish science has thus lost one of its outstanding founders and organisers, and our hydrobiological community, a spiritual and moral guide, a wise, patient and very indulgent guardian.

Professor Bogucki was born in Łódź in 1884. In this town he attended gymnasium from which he was dismissed for participating in the preparation of a school strike against the russification of Polish education. After taking his matriculation, he studied in Kraków from 1905 to 1907. During this period, he spend more than half a year in a Warsaw prison in connection with his revolutionary activities in the Polish Socialist Party, after which he was forced to leave the country and he finished his studies on natural sciences in Paris in 1911. On his return to Poland, he was appointed to an assistantship in the Department of Biology and Embryology in the Jagiellonian University of Kraków in 1912. In August 1914, patriotic feelings led Professor Bogucki to volunteer to the Polish Legions; after one and a half years of service, he returned to the Jagiellonian University, gained his doctorate in 1916 and left for Warsaw to work as assistant in the Department of Histology and Embryology in the University during the years 1917 to 1919 and, until 1932, in the Department of Physiology in the Nencki Institute, where he also acted as the Institute's secretary. In 1920, another interruption of the Professor's scientific work occurred due to war service. However, he soon re-assumed his duties and during the years 1920—21, lectured in embryology in the University „Wolna Wszechnica" and later, in the Medical Faculty of the Stefan Batory University in Wilno. He was qualified as docent of the University of Warsaw in 1928.

In 1932, Professor Bogucki started to organise the Marine Station at Hel near Gdynia. Later, his travels abroad in order to become acquainted with the organisation and equipment of various European marine stations facilitated his work of planning a new laboratory at Gdynia, which was subsequently built and now houses the Marine Fisheries Institute. Professor Bogucki directed the scientific activity of this station until the eruption of the Second World War and, from 1934, he was also director of the Nencki Institute in Warsaw. In 1938 the title of Titular Professor was conferred upon him.

During the nazist occupation Professor Bogucki was in Warsaw. And again, as before, during this difficult period for our nation, the Professor found means of expressing his patriotism. He lectured on the physiology of man to medical students in the secret underground university and later after the Warsaw Insurrection of 1944, when he found himself in the district of Skierniewice he again joined in the local underground organisation for tuition of students. Already before all war activity had stopped, in April 1945, Profes-

sor Bogucki re-established active marine research in Gdynia in the same laboratory but called the Marine Laboratory of Fisheries and later he also directed the work in the Department of Ichthyology in this laboratory, later re-named the Marine Fisheries Institute. In 1951, as a result of the infamous tendency of this period, he was displaced as director of Marine Fisheries Institute (in 1957 this decision was reversed). From this period, he worked in the Nencki Institute first as a self-dependent scientific worker, then as an extraordinary professor (from 1954) and later as an fully established ordinary professor (from 1959); from 1963 he was chairman of the Scientific Council of the Institute.

The scientific activity of Professor Bogucki begins more than fifty years ago. His first published paper concerning the regeneration of the male genital glands in salamander appeared in 1914; he found that these glands had the capacity to regenerate completely and to attain the maturity independently on the stage they were extirpated. He then worked on the influence of castration on cyclic structural changes in the ovaries of frogs. Then appears a whole series of papers concerning experimental parthenogenesis in amphibians and echinoderms. These contributed considerably to the role of mechanical stimuli in the initiation of traumatic parthenogenesis and also of the influence of physiologically active cells coming from different organs on the development of unfertilised eggs.

From 1930, Professor Bogucki directed his interest towards problems of adaptive mechanisms and, in particular, towards the problem of adaptation of animals to life in brackish waters. His work on the osmoregulation of salmon eggs augmented existing information on the permeability of egg membranes to electrolytes and colloids, on the changes in internal osmotic pressure and on the inhibition of development of peri-vitelline cavity under the influence of a hypotonic external medium. Studies on the regulation of osmotic pressure and the mineral composition of the haemolymph of the idoteid (*Mesidothea entomon*) and the crayfish (*Astacus fluviatilis*) were the continuation of his work on osmoregulation. He showed that the osmotic pressure of the haemolymph of the Baltic idoteid was not only more than twice as high as in its normal biotope but also both the concentration and proportion of electrolytes of the haemolymph were different from Baltic sea water. Both these animals were able to adapt to a wide range of salinities and could osmoregulate to a considerable extent in diluted sea water. Although, on transfer to sea water, the crayfish responded with an increase in its haemolymph electrolyte concentration, up to a certain limit, the relative proportions of the blood electrolytes remained unchanged. These results belong to the world's classical literature on the problem of osmoregulation.

A widening of the range of Professor Bogucki's achievements was his work on the reproductive and developmental biology of the meduse *Aurelia aurita,* and, carried out just after the last war, his similar research on *Mesidothea. Aurelia aurita* is a permanent member of the Baltic fauna and there it goes through its whole life cycle.

After the war, Professor Bogucki continued and developed investigations on the biology of brackish water animals, particularly concentrated on the polychaete *Nereis diversicolor,* on its ecology, development and adaptation to diluted sea water and fresh water. The results from this work are manifold,

concerning the structure of tunnels, behaviour, sensitivity to stimulation, the period and mechanism of reproduction, the rate of development in waters of different salinity, sexual maturation and the life span of this polychaete. The work on nereid development in diluted sea water and fresh water is fundamental and may be treated as a model of excellent experimental work, where laboratory investigations are based upon field observations, the applied experimental methods are elegant, very delicate, and the patient repetition of experiments went hand in hand with care and precision in drawing conclusions. This work showed that *Nereis diversicolor* can penetrate and live to an old age both in brackish and fresh water but it is able to reproduce only in brackish water of a fairly high salinity, because its trochophores and 1—3-segmented larvae do not survive in fresh water.

Elucidation of the physiological mechanisms of nereid adaptation to changes in the osmotic properties of its environment was the subject of the last studies of Professor Bogucki, usually in collaboration with Dr. A. Wojtczak. Maturation of the nereids sexual products revealed to be independent on the concentration of the external medium and was normal even in animals adapted to fresh water. Nereids from around Gdynia revealed a considerably higher adaptive capacity to survive in diluted medium than those from waters of higher salinity. Their isolated muscles have a greater resistance against the hypotony of external medium and tissues of undamaged worms, when placed in diluted environment, reveal a very low increase of hydratation.

The rich, diverse but uniform scientific achievement of Professor Bogucki is completed with two monographic sections on nereids and on idoteids, as well as a popular book on marine biological stations.

So great was the activity of Professor Bogucki in initianing and leading in Polish hydrobiology and so natural but discrete his influence on, at least, two generations of water biologists that we do not always remember just how much he contributed to the organisation of this sphere of science of Poland. A great part of that what has been carried out in marine biological research is based on Professor Bogucki's efforts; we owe a debt of gratitude to him not only for creating the material basis for the present Marine Fisheries Institute but also for improvement of its today leading scientists. To the very end, he acted as intercessor in the development of marine biological research in Poland and did not cease in his efforts to founding the marine biological station in which would be carried out the fundamental research which is the basis of good economic management.

The organisational reconstruction of Polish hydrobiology after the last war greatly occupied Professor Bogucki. Between the years 1955 and 1960 he was chairman of the Hydrobiological Committee of the Polish Academy of Sciences and also was active in the establishing of the Polish Hydrobiological Society; from 1953 until the end he was editor of the „Polskie Archiwum Hydrobiologii" (Polish Archives of Hydrobiology) and from 1956 he was not only the editor of the second journal published by the Nencki Institute, „Acta Biologiae Experimentalis" but also from 1955 to 1957 he edited the biological section of the Polish Analytical Bibliography of the Polish Academy of Sciences. The generation of young hydrobiologists starting scientific work during the last twenty years owe a particularly great debt of gratitude to Professor Bogucki. He was greatly concerned with creating the best possible

conditions of work by supporting the establishment of the existing posts, by making possible abroad studies and by organising of congresses and symposia which facilitated wide scientific contacts and the exchange of scientific information. His work as editor of the „Polskie Archiwum Hydrobiologii" was much harder than normal duty of this kind, but he always found time for friendly help and advice to young authors.

All acknowledged the learning and worth of Professor Bogucki and this acknowledgement has already been expressed in public. The Scientific Associations from Warszawa, Łódź, and Gdańsk, Polish Zoological Society, Polish Physiological Society and the International Association of Limnology (Societas Internationalis Limnologiae) nominated him as one of their members. The Polish Hydrobiological Society ceremoniously bestowed honorary membership upon him. Already before the war and for many years after the war, Professor Bogucki represented Poland at the International Council for Marine Research. The Ministry of Navigation, the Marine Fisheries Institute and the Laboratory of Water Biology of the Polish Academy of Science all nominated him as member of their Scientific Councils. The Communal Council of Gdańsk bestowed upon him the town prize for scientific work and the Association for the Development of Western Territories dignified his activities as meritorious. The Polish Government distinguished Professor Bogucki with the Cross of Independence and the Cross of Polonia Restituta.

The death of the Professor is felt particulary by those who were in daily contact with him over many years. We sadly feel the loss of a man who to the last days of his life openhandedly and with all his heart gave help, counsel and friendship.

The Editor

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SOME CONSIDERATION OF THE OMSOTIC AND IONIC REGULATION IN POLYCHAETES

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ABSTRACT

Of the six species of polychaetes occurring in the brackish waters of Adyar, salinity tolerance was greater in two Eunicid species, *Marphysa gravelyi* Southern and *Diopatra variabilis* (Southern) than in *Glycera embranchiata*, *Onuphis eremita*, *Loimia medusa* or *Clymene insecta;* the distribution of these species in the Adyar estuary also reflected this difference.

In polychaetes, such osmotic independence as they possess results from either 1. passive tolerance (*Marphysa gravelyi, Diopatra variabilis*), 2. volume or weight control (*Nereis diversicolor, Perinereis cultrifera, Nereis virens*), 3. reduction in permeability (*Nereis diversicolor*). Regulation of organic constituents such as amino acids is not uncommon among polychaetes.

CONTENTS

1. INTRODUCTION

Penetration of brackish waters or regions of lower salinity has been accomplished by several animal phyla including the polychaetes. Though predominantly marine, a few like the Nereids, to which family belongs the most often investigated and celebrated *Nereis diversicolor*, have successfully established themselves in regions where changes both in salinity and temperature are usual. Yet others, like the Glycerids and the Nephthids, have been reported even from fresh water (Wesenberg--Lund 1958; Southern, 1921). Such independence over the environment has been made possible by mechanisms for osmotic and/or ionic regulation. Factors like (1) passive tolerance of the tissues to lowered salinities; (2) volume or weight control; (3) reduction in permeability; (4) production of hypo- or isosmotic urine etc., have in varying degrees contributed towards the maintenance of a relatively constant

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m i l i e u   i n t e r i e u r (BERNARD 1885 *), without which passage from the sea
brackish or fresh water would have been impossible. Study of such species and
the factors contributing to their successful survival would aid in the elucidation
of problems associated with the colonisation of such diverse media as the brackish
and fresh waters.

2. SALINITY TOLERANCE AND DISTRIBUTION

Polychaetes have been observed in various localities involving consider-
able dilution of the sea water (FLORENTIN 1899; FERRONNIERE 1901; ANNAN-
DALE 1922; DEHORNE 1925). PEARSE (1928) examining 18 species of polychae-
tes found that only two viz., *Laonice viridis* (VERRILL) and *Nereis virens*
SARS, could live and be active „for periods of two to three weeks in one
fourth sea water, but died in weaker solutions". *Nereis virens* collected from
brackish waters of the River Narraguagas, were able to withstand 2%/o dilu-
tion of the sea water, whereas the same species from the open sea could to-
lerate only 7%/o dilution (TOPPING, FULLER 1942). *Glycera dibranchiata* became
swollen and turgid even in 50%/o sea water, the integument bursting in gre-
ater dilutions. On the basis of their tolerance, TOPPING and FULLER (1942)
have accounted for the distribution of these polychaetes in the estuary of the
River Narraguagas. The distribution of *N. diversicolor* in the Isejford may
have been governed by „competition and/or predation by another species of
nereid" (SMITH 1955b), but that it is certainly not a „factor of over-riding
importance" both at Tames Bay, Millport (SMITH 1955a) and in the Tames
estuary (SMITH 1956), is too evident. The zonation of *N. diversicolor* in the
above two areas appears to be accounted for on the basis of salinity toleran-
ce. *Neanthes lighti,* another nereid polychaete, although could be adapted to
fresh water in the laboratory, is restricted to the estuarine or lacustrine situ-
ations in the Salinas River estuary, California (SMITH 1953). A zoogeographi-
cal survey (KRISHNAMOORTHI 1963d) of the Adyar brackish waters with part-
icular reference to the distribution of six species of polychaetes, has reve-
aled that, while *Glycera embranchiata* and *Onuphis eremita* occur near the
mouth in the intertidal sands where conditions are predominantly marine
(35‰), are not present in the estuary; *Loimia medusa* is confined to marine
dominated regions (30‰ to 34‰) of the estuary at Station A only, and *Clyme-
ne insecta* and *Diopatra variabilis* occur in the upper reaches of the estuary
along with *Marphysa gravelyi* i.e., at Station D, where the salinity ranges
from 20‰ to 26‰. *M. gravelyi* has a more cosmopolitan distribution occurring
at all stations from Station C to Station F, where the salinity ranges from
5‰ to 28‰. The variations in the distribution of these polychaetes have been
explained as due to the differences in their abilities for salinity tolerance.
Further, experiments on the rate of mortality in hypoosmotic media have
revealed that it not only increased with the period of exposure but also with
increasing dilution (KRISHNAMOORTHI 1962). In 24 hours in a medium of 18‰,
G. embranchiata suffered the maximum rate of mortality of 26%/o. *C. insecta*
with only 12%/o showed the minimum mortality. *L. medusa* and *O. eremita*
with respective mortality rates of 24%/o and 22%/o ranked between the two pre-
viously mentioned species. At the end of 48 hours all the four species exhibi-

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* Quoted by BARCROFT, J. in: *Features in the architecture of physiological
function.*

ted an increased rate of mortality until 96 hours when 98% of *G. embranchiata*, *O. eremita* and *L. medusa* were dead. *C. insecta* alone reached only 26% mortality. The rates and the trend of mortality were similar in other dilutions of salinities 16‰ and 10‰. *C. insecta* showed better capacities for survival. They reached as high as 98% in a dilution of 10‰ and that at the end of 96 hours (KRISHNAMOORTHI 1962). In contrast to the above species are the Eunicids, *Marphysa gravlyi* and *Diopatra variabilis*. While the former species could survive a medium of salinity of 5‰ without any ill effects (unpublished data), 67% of the latter species died at the end of 96 hours in a medium of salinity of 12‰ (KRISHNAMOORTHI 1963b). The extent of tolerance of reduced salinities, therefore, could be a yard stick to judge the distribution of a species in regions of fluctuating salinities.

3. VOLUME REGULATION

It is common knowledge that the responses to hypoosmotic and hyperosmotic media are different in different polychaetes as seen in *N. diversicolor* and *N. cultrifera* (BEADLE 1931, 1937; SCHLIEPER 1929a, b, 1935) and *N. virens* (SAYLES 1935). *N. diversicolor* being en euryhaline form showed better powers of volume regulation than either *N. cultrifera* or *N. virens*. When such studies were extended to four species viz., *G. embranchiata*, *O. eremita*, *L. medusa* and *C. insecta*, it was seen that both in their capacites for volume regulation and tolerance to hypoosmotic media, they showed differences (KRISHNAMOORTHI 1962). All of them, without exception, increased in volume at the end of the first hour when subjected to the stresses of hypoosmotic media. But the extent of increase varied from one species to the other. All but *G. embranchiata*, began to decrease in volume reaching a final volume which was maintained constant even over a period of 24 hours. However, the final volume attained at the end of 4 hrs., differed once again from species to species (Fig. 1). Thus, both the initial increase in volume and the final volume attained was the lowest in *C. insecta* and the highest in *G. embranchiata* and *O. eremita*. *L. medusa* ranked between the two. Increase in volume is less in euryhaline than in stenohaline forms (PROSSER et al. 1950; JØRGENSEN, DALES 1957). In brackish water organisms swelling is followed by volume regulation as reported in a number of polychaetes (BEADLE 1931, 1937; ELLIS 1933, 1937, 1939; JURGENS 1935; SAYLES 1935). From the distribution of these species, it is clear that while *G. embranchiata*, *L. medusa* and *O. eremita* were confined to marine dominated regions of the estuary, *C. insecta* was restricted to the brackish water regions of the estuary. Since volume regulation is better developed in *C. insecta*, it is, therefore, small wonder that this species has penetrated far higher up the estuary where the waters are all brackish. Volume regulation, therefore, constitutes a distinct mechanism conferring upon the possessor an ability to withstand fluctuating salinities far better.

4. PERMEABILITY AND SALT UPTAKE

Passive tolerance of dilute media and/or volume regulation, although advantageous in themselves, can but have limited significance for a passage into brackish water regions, unless accompanied by a reduction in permeabi-
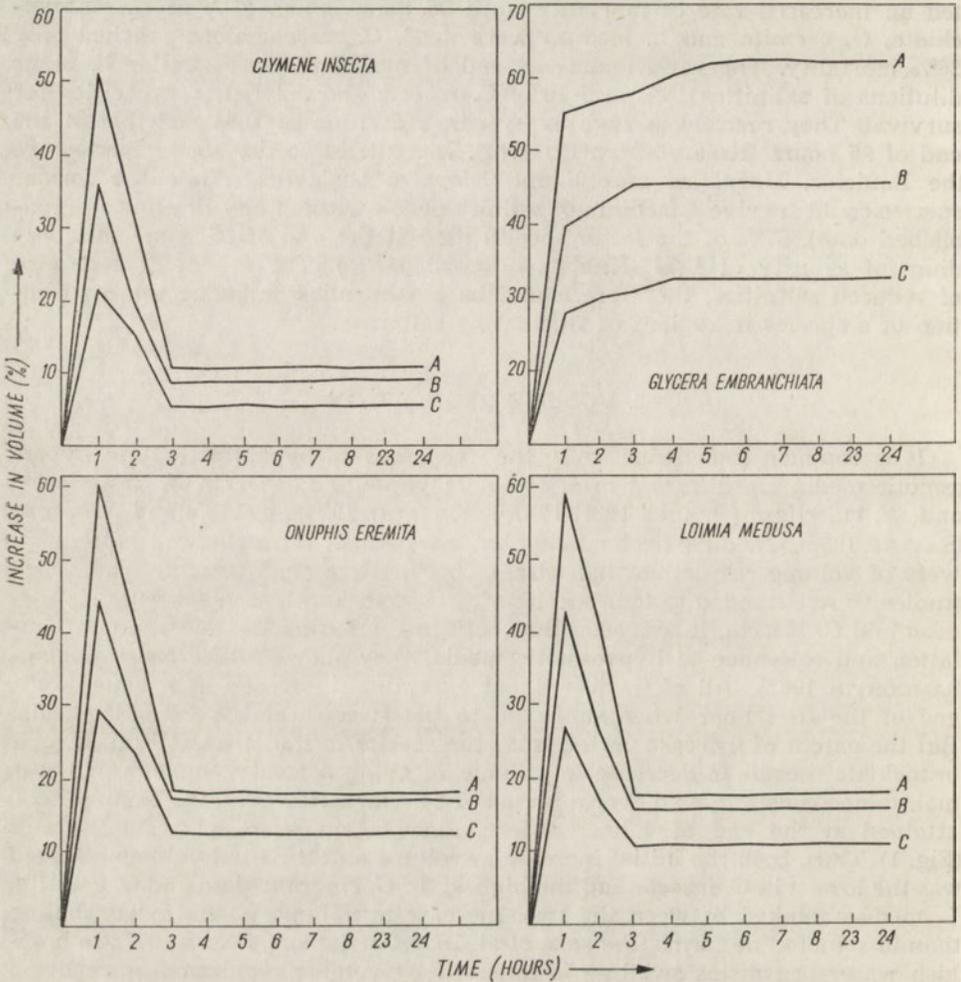
Fig. 1. Volume changes in four species of polychaetes in three hypoosmotic media (A—8.62‰, B—13.7‰, C—20.7‰) during different intervals (from: KRISHNAMOORTHI, 1962)

lity. Although direct evidence of reduced permeability in the above forms is not available, the variations in volume control indirectly indicate the extent of permeability. Among the forms studied, in *M. gravelyi* both the initial increase in volume and the final volume attained at the end of 4 hrs., were the minimum (unpublished data). The others showed varying degrees of volume control depending upon whether they were stenohaline or euryhaline (KRISHNAMOORTHI 1962, 1963b). That the rate of chloride exchange and the permeability to water were lower in the euryhaline *N. diversicolor* than in either *N. pelagica* or *N. (virens) southerni* was demonstrated (BETHE 1934; JØRGENSEN, DALES 1957). FRETTER (1955) also found in *N. diversicolor* a lower [24]Na exchange than in *P. cultrifera*. Form the above evidence it is reasonable to

accept that *M. gravelyi* with its pronounced euryhalinity and better volume control would evince reduced permeability to water. But reduced permeability alone is insufficient for life in media of lower salinities. Salt uptake is necessary for the maintenance of a constant m i l i e u   i n t e r i e u r. *N. diversicolor* maintains an internal osmotic pressure higher than that of the outside medium (Schlieper 1929a, b; Beadle 1937) and this, Jørgensen, Dales (1957) observed, was due to active uptake of salts from the medium. While Ellis (1937) from his studies on the same species (*N. diversicolor*) from Plymouth and Roscoff, found no active regulation, Zenkevich (1938a, b) found, in forms collected from different localities, an ability to maintain a higher osmotic pressure. Considering that an effective salt-loss mechanism as obtained in *N. succinea* compared with *N. diversicolor* and *N. limnicola,* could also be of survival value in sudden exposures to low salinity (Smith 1963b), the role of reduction in permeability appears to be of doubtful significance. However, until more knowledge of the role of the body wall and the nephridia is gathered, it would indeed be premature to hazard a significance to any one of the above factors.

· 5. ROLE OF NEPHRIDIA

Control over the concentration and quantity of urine is yet another factor contributing to the colonisation of brackish and fresh waters. This has been well demonstrated among Crustaceans (See review by Lockwood, 1961) and not reported in polychaetes so far and such evidence as is available is only circumstantial. Taking into consideration the fact that the more swollen worms (*N. diversicolor*) and of higher internal hydrostatic pressure, were able to concentrate their body fluids more rapidly in an isosmotic medium than the less swollen worms, Beadle (1937) concluded that there was some circumstantial evidence of the formation of urine hypotonic to the blood. The relatively greater loss of chloride in *N. diversicolor* when transferred to hypotonic solutions as compared with that in *P. cultrifera* (Ellis 1939) and the greater permeability to ^{36}Cl in the former species than in the latter, led Jørgensen and Dales (1957) to argue that these factors might contribute to the excretion of blood-isotonic urine. It is conceivable, therefore, that the kidneys would exhibit structural modifications and size differences accompanying the production of isotonic or hypotonic urine since the importance of nephridia in volume regulation was demonstrated in the estuarine fan-worm, *Sabella pavonina,* by Ewer and Ewer (1943). Krishnan (1952) found in comparable species of Nereidae, that in *Lycastis indica,* a fresh water polychaete, the nephridia were larger in size and better vascularised than those of the stenohaline *Perinereis nuntia.* A study of the histology and morphology of nephridia in *G. embranchiata, O. eremita, L. medusa* and *C. insecta,* has revealed that while *G. embranchiata* possessed nephridia of the protonephromixial type with simple solenocytes performing the function of excretion, the rest of the species had nephridia of the mixonephridial type. Furthermore, the extent of the excretory surface available for excretion and the blood supply the nephridia receive, were less in *O. eremita* than in *C. insecta. L. medusa* ranked between the two. Such a comparison was not possible in the case of *G. embranchiata* as the cells forming the nephridium were syncitial in nature. Perhaps, the failure of regulation in *G. embranchiata* is a direct consequence of the kind and structure

of the nephridia. It also argues, therefore, that formation of hypo- or isotonic urine is more to be expected in *C. insecta* than in either *O. eremita* or *L. medusa* (KKRISHNAMOORTHI 1963a). However, as observed earlier, conclusive evidence provided as by his classical experiments on Oligochaetes (RAMSAY, 1949a, b), of the formation of hypo isotonic urine in brackish water polychaetes is not yet available.

6. IONIC REGULATION

ELLIS (1937) from his studies of the water and electrolyte exchange in *N. diversicolor* came to the conclusion that the weight regulation was not accompanied by osmotic regulation. BEADLE (1937) also was of the opinion that since the degree of osmotic regulation was relatively slight, it could not be considered of direct importance for survival in dilute sea water. Isolated muscle preparations of the euryhaline *N. diversicolor* continued to function in dilute sea water better than those of either *Arenicola marina* or *Perinereis cultrifera* (WELLS, LEDINGHAM 1940a). This as BEADLE (1957) says "throws doubt on the survival value of its powers of osmotic regulation". Similar studies on whole anterior ends of *M. gravelyi* SOUTHERN have shown spontaneous and sustained activity in dilutions ranging from 20% to 50% sea water of salinity 34‰ (KRISHNAMOORTHI, KRISHNASWAMY 1963). Perhaps, the answer to their ability to tolerate hypotonic media may have to be sought elsewhere and their capacity for ionic regulation, a field little investigated in polychaete physiology, would provide the answer. CCLE (1940) found that *Amphitrite brunnea* and *Glycera dibranchiata* had considerable powers of ionic regulation. *Arenicola marina* has no osmotic control but in dilute sea water the concentration of K had become 118%, of Ca 113% and of SO_4 90% of the same ions in the external 75% sea water (ROBERTSON, 1949, 1953).

7. OXYGEN UPTAKE

To maintain a difference of osmotic pressure between the body fluids and the surrounding medium, energy must be expended and it might be expected that oxygen would be concerned TARUSSOV (1927) found by Co_2 measurements that the respiratory rate of *N. diversicolor* increased in hypotonic and decreased in hypertonic sea water. From his earlier experiments on *N. diversicolor* and *N. cultrifera*, BEADLE (1931) was inclined to agree with SCHLIEPER'S (1929a, b) hypothesis that the respiratory rate of *N. diversicolor* increased in dilute sea water progressively with the lowering of the salinity and this effect was not so marked in *N. cultrifera* which could not resist the inflow of water at low salinities. He was further inclined to agree with SCHLIEPER'S (1929a, b) second postulate that it was by virtue of this extra oxygen consumption that the difference of osmotic pressure between the water and the body fluids was maintained. This apparent connection between respiration and active regulation was demonstrated also in a number of crustaceans (MARGARIA 1931). In the light, however, of later experiments on *N. diversicolor*, BEADLE (1937) doubted the connection between the oxygen consumption and osmotic work since there was no "obvious relationship between weight changes and

internal concentration". It is possible that the increase in oxygen uptake is due to hydration of muscles as suggested by PIEH (1936) from experiments on *Carcinus maenas* and *Eriocheir sinensis.*

8. COMPENSATORY MECHANISMS

Recent studies have shown that there are compensatory mechanisms coming into play enabling adjustment of the osmotic pressure of the cells on a par with the variations in the concentration of the body fluids. WILBER (1948) and WILBER and MacDONALD (1950) found in *Amphitrite ornata,* a polychaete, that the glucose content increased not only with the length of exposure but also with the increase in the temperature and suggested the nervous tissue as the possible source of glucose stored as glycogen, as has been found in a number of crustaceans and molluscs (SCHALLEK 1949). The amino acid content of *Arenicola marina*, a poikilosmotic annelid, on transference from 100% to 50% sea water, dropped from 331.2 to 150.6 mM/kg of fresh tissue. DUCHATEAU-BOSSON et al. (1961) are of the opinion that this fall is sufficient to account for 40% of the change in osmotic pressure and is adequate to ensure that the hydration is increased by only about 50%. FLORKIN (1961), JEUNIAUX et al. (1961a, b) showed that the intracellular adjustment of the osmotic pressure is also a function of euryhalinity in *N. diversicolor* as compared with *A. marina* and *P. cultrifera.* Although the polychaetes are essentially ammonotelic, some traces of urea have been reported without comment in the coelomic fluid of *Arenicola* (STRUNK 1932; WILBER 1948).

9. OSMOTIC REGULATION AND TEMPERATURE

In a study of osmotic regulation in estuarine species the importance of temperature must be considered, as was well demonstrated by BROEKEMA (1942) in *Crangon crangon*; by BBROEKHUYSEN (1939) in *Carcinus maenas* and in several animals by WIDMANN (1936) and WIKGREN (1953). In the tropics the abundance of estuarine fauna has been explained in terms of the hypothesis of von MARTENS (1858) that "the relative evenness of temperature of tropical waters, characterised by the absence of periods of sharp winter and the presence of large rivers opening into the sea and by heavy rainfall, has been the main contributory cause of the development of a rich estuarine fauna" (quoted from PANIKKAR 1951). VERWEY (1957), however, agreeing with PANIKKAR's (1951) conclusions that colonisation of tropical brackish waters by marine animals may have been made possible for all those species "that withstand low salinities better at high than at low temperatures", comments that "until now there are few exact data on this point". *Nereis limnicola* (= *Neanthes lighti*) which resembles *N. diversicolor* in its pattern of chloride regulation (SMITH 1957), controlled their volume in pond water and 1/20 sea water at 13°C. But at 1°C and 2°C volume control in freshwater or 1/20 sea water, broke down (SMITH 1959). SMITH (1957) found also that it *(N. limnicola)* could not maintain the usual chloride level of its coelomic fluid at temperatures near zero. KINNE (1954, 1958a) observes that *N. diversicolor* survived better in high than in low salnities at high temperatures.

Could this mean that at higher temperatures the minimum osmotic pressure of blood compatible with life would be lower and hence the osmotic work required in maintaining hypertonicity is less, as observed by PANIKKAR (1940).

10. PHYSIOLOGICAL RACES

From the foregoing account it should be, by now, fairly obvious that different species exhibit different capacities for osmotic regulation. It is conceivable, therefore, that the same species collected from different geographical situations might exhibit different physiological performances. *N. diversicolor* collected from Roscoff showed a weight regulation different from those collected from Bangor (ELLIS 1935). This difference, ELLIS (1935) concluded, was racial and not due to environmental factors. The question whether there were physiological races of *N. diversicolor* was more closely examined by SMITH (1955) by comparing the level of chloride regulation in worms collected from different parts of its geographical range, since chloride is the major ion of the body fluid, the one least subject to ionic regulation (ROBERTSON 1949). His results showed a uniform pattern and level of chloride regulation regardless of the region of origin and, coupled with the failure of *N. diversicolor* to populate oligohaline waters in Finland, led him to conclude that the differences were an consequence of local seasonal hydrographic factors rather than an indication of physiological races. An interesting instance of physiological isolation by salinity tolerance has been recently reported for *N. diversicolor* in certain Rumanian lagoons (PORA, ROSCA 1952). Separated from the Black Sea by sand banks over a period of 40 years these lagoons have reached a salinity of 62‰. Adult *N. diversicolor* collected from these lagoons could not survive when transferred to the Black Sea, nor could worms from Black Sea tolerate the lagoon water. The ability of brackish water populations of polychaetes to become acclimated to different salinity regimes is remarkable, as witnessed by the polychaete *Neanthes succinea*, which on transplantation into the Black Sea, starting with 65 000 worms in 1939—41, has grown to such large proportions as to equal the contents of a freight train 72 miles long (ZENKEVICH 1957). The problem of "physiological races", therefore, needs a cautious approach.

11. OSMOTIC REGULATION THROUGH ONTOGENY

Physiological studies on polychaetes have so far been mainly concerned with investigations on the behaviour of adults. These studies, valuable as they are in their contribution towards the knowledge of polychaete physiology, can give but a partial picture. It is, therefore, necessary that such studies are extended all through the ontogeny of a species to obtain a complete picture of the regulatory mechanisms of a species as a whole as remarked by BEADLE (1957). In this regard, the experiments of BOGUCKI (1954) are very interesting. He cultured *N. diversicolor* in seawater of 7‰ salinity and subjected various developmental stages to further dilutions. He found the pre-larval and larval stages were most susceptible to salinity changes, while young worms could survive in freshwater for several months. The adults were not so resistant. The eggs of *M. gravelyi* SOUTHERN isolated from their jelly coats,

behaved like osmometers increasing in volume in dilute media and decreasing in hypertonic media. The larvae of the metatrochophore stage showed slight improvement in the tolerance of dilute media. A progressive increase in the tolerance of dilute media was noticed in the next stage viz., the nectochaetae stage, while the adults could tolerate salinities over a wide range (KRISHNAMOORTHI 1951a, b). Another Eunicid, *Diopatra variabilis,* behaved in a manner similar to that exhibited by *M. gravelyi.* A progressive increase in the tolerance of hypoosmotic media was noticed through the egg to meta-trochophore to nectochaetae to the adult stages (KRISHNAMOORTHI 1963b). Perhaps, as observed by BEADLE (1957) a chemical analysis of the developing regulatory mechanisms would give an insight into the "embryology" of osmotic and ionic regulation, a field so far little investigated.

In short, the process of adaptation of an estuarine species to heterosmotic conditions is far too complicated needing investigation not only at the tissue level but also at the cellular level. Here is an opportunity both for the biologist and the student of physical sciences to explore a rich field requiring techniques of not only analytical chemistry but biophysical assays for the resolution of many intricate problems that are bound up with polychaete adaptations to estuarine conditions. In spite of the accumulation of a vast knowledge on the behaviour of polychaetes, yet very little is known about the mechanisms of adjustments, the sites of these mechanisms etc. In the light of the preceeding account an investigation into the physiology of polychaetes that have successfully established themselves in an estuarine habitat cannot but be fascinating.

12. SUMMARY

Polychaetes are predominantly marine. But reports of the Nereids, the Glycerids, the Eunicids and the Nephthids from both brackish and fresh water are available. Factors like (1) passive tolerance; (2) volume or weight control; (3) reduction in permeability; (4) production of hypo- or isosmotic urine etc., have in varying degrees contributed towards such independence gained by them. Of the six species occuring in the brackish waters of Adyar, salinity tolerance was greater in the two Eunicids, *Marphysa gravelyi* SOUTHERN and *Diopatra variabilis* (SOUTHERN), than in either *Glycera embranchiata, Onuphis eremita, Loimia medusa* or *Clymene insecta.* This ability to tolerate a wide range of salinity was intimately associated with their pattern of distribution in the Adyar estuary. The extent of tolerance of reduced salinities, therefore, could be a yard stick to judge the distribution of a species in regions of fluctuating salinities. Among polychaetes control over volume/weight is also well developed as witnessed among the Nereids, *Nereis*

diversicolor, Perinereis cultrifera and *N. virens.* Volume regulation, therefore, has constituted a distinct adaptive mechanism among polychaetes, conferring upon the possessor an ability to withstand fluctuating salinities far better. Matching with these abilities, is the reduction in permeability as seen in *N. diversicolor,* but present to a very limited extent in *N. virens* and *P. cultrifera.* Among hyper-regulators, like *N. diversicolor,* there is, understandably, a mechanism for uptake of salts without which maintenance of relatively constant *milieu interieur* would be impossible. Although there is circumstantial evidence of formation of hyposmotic urine in *N. diversicolor,* the quantity and the concentration of urine produced, have not been demonstrated beyond doubt generally in polychaetes, much less in *N. diversicolor.* That the nephridia are generally bigger in the more euryhaline polychaetes is shown. Whether size could be associated with the formation of hypo- or isosmotic urine, though conceivable, is speculative because of lack of studies on the physiology of nephridia of polychaetes. There is also, among polychaetes, ionic regulation. But its specific role in the physiological adaptation of a polychaete species, is yet uninvestigated. Regulation of the organic constituents like the amino acids, the glycogen etc., in the body fluids in response to fluctuations in the environmental parameters, is not uncommon among polychaetes. But the significance and the nature of these adjustments are little understood. However, among polychaetes too, there appears to be not only a response at the tissue level but an adjustment at the cellular level to meet the exigencies of a changing environment. Similarly very little is known about the energetics of osmotic and ionic regulation in polychaetes, although oxygen uptake has been reported in *N. diversicolor.* Likewise, there is an urgent need to study osmotic and ionic regulation all through the ontogeny of a species to gain a fuller insight into the "embryology" of these twin phenomena and to understand better the intimate association of a polychaete species as a whole, with the ecological niche it has chosen to live in.

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ADDENDUM

The following publications have appeared after the present paper had been sent to press:

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They have, while bringing into focus some of the thoughts given expression to in the paper, helped to emphasize the need to fill the many lacunae yet present in our knowledge of polychaete physiology.

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POTASSIUM IN POLISH CARP PONDS

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ABSTRACT

From 900 water samples was determined the potassium content of various carp
ponds, the range of potassium concentrations in polluted waters (0.0—9.0 mg/l) as
well as the relationship between the potassium content of a pond and its produc-
tivity. The most frequent values of potassium occurring in Polish ponds was between
2 and 4 mg/l. It was found that the potassium content varied very greatly seaso-
nally but remained at much the same level threughout a 10-year period.

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2. Material and method
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1. INTRODUCTION AND PROBLEM

Among the biogenic elements that enter into composition of a plant-cell
potassium takes a foremost rank. From all cations taken by plants the quan-
tity of potassium is the largest one, and its role in nutrition as well as in
many other vital processes of plant-life (division of cells, transpiration, pho-
tosynthesis, metabolism of albumen and sugars, enzymatic activity) is inreplaceable
though not wholly understood (*Encyclopedia of Plant Physiology*, IV, 1958). Ruttner
recently (1962) states that "metabolism of magnesium, potassium sodium and alu-
minium... is very little known".

The difficulty and complication of the method for determining that cation was
mainly responsible for the considerable gaps in characterizing its quantitative occur-
rence in surface waters and especially in or knowledge of its dynamics.

Potassium relations are best known in lakewaters. In the majority of 167 lakes
in Sweden Lohammar (1938) found potassium from trace quantity up to 3.0 mg/l.
Järnefelt (1963) in finnish lakes determined its content as 0.6—3.3 mg/l K and as
average quantity 1.5 mg/l K. Kuizel (1936) found this component in the zurich lake
from 0.4 to 2.1 mg/l K. Thomas (1949) in his regional studies on 25 lakes of North

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Switzerland (belonging to various limnological types) records a winter content of potassium going from 0,6—4,0 mg/l K. American papers (LOHUIS et al. 1938) give the content of potassium in the lakes of Northern Wisconsin within the limits of 0.24—2.39 mg/l K, mostly below 1.0 mg/l K.

OHLE's (1939/40) work gives a method for determining potassium, as its content in the lakes of eastern Hollstein (1.3—9.5 mg/l K) its stratification, and its positive correlation to alkalinity. This work divides lakes into three categories: poor in potassium (less than 2.0 mg/l K), medium-rich (2.0—3.0 mg/l K) and rich (above 3.0 mg/l K).

HÖLL's materials (1950) give in general small values of potassium (mostly 0.8—1.0 mg/l K) characteristic for oligotrophic lakes (alpine lakes, Norway and Swedish mountain-lakes). The smallest content found by this author was 0.4—0.5 mg/l K, attaining nowhere analytical zero. With the growing eutrophy of the lakes the author found also larger quantities of potassium (1.5—2.0 mg/l K), which in the strongly eutrophic waters of North Germany varied from 5.0 to 6.5 mg/l K. according to this author greater quantities may indicate pollution.

For river-waters the highest content of potassium — 130 mg/l K — was given by SCHMIETZ (1950). This high quantity was due to waste out flows from potassium-salt mines, situated at the confluence of the rivers Wipper and Werra.

The above mentioned and some other works enabled HUTCHINSON (1957) to make a list, in which the author gives the mean percentage of chemical equivalents especially that of potassium of the surface waters of the world as follow: Wisconsin lakes — 4.8% of all cations, Upper Sweden lakes — 2.2, North Germany lakes — 6.7, Rivers — 3.4, Central European waters — 1.9.

In Poland, the first determinations of potassium content in river and lake waters of the country were made of the Institute of Limnology and Fishery of the Higher School of Agriculture (WSR) in Wrocław, in the years 1952—54. Some years later STANGENBERG (1956) determined the most frequent rate of occurrence of potassium in lakewaters of Poland as 2—6 mg/l K, and the quantity of this component most often met with in river waters (1958) as 2—4 mg/l K.

Its quantity in the Mazury-lakes was given by PATALAS (1960) as 0.4—5.6 mg/l K. most often 2—4 mg/l K.

The relatively little knowledge of the processes connected with mechanism of circulation of potassium in water medium was augmented by RODHE's work (1948), which discussed the role of potassium as a nutritive factor for algae and which denies its limiting influence upon their production.

SOLSKI (1962) on discussing the problem of liberating potassium from some water plants and the influence of some factors (age of plants, light, development, desication, trituration of material, microorganisms) upon the rate of speed of this process, stated, that potassium is one of the cations that may be most easily washed away from plants. After 24 hours the maximal quantity of potassium leached away from a fresh *Typha latifolia* was 95.5%. Temperature had no effect upon the leaching process from 0—26.5°C. Young plants in spring had the most rich potassium content. The intake of potassium through microorganisms from leached water-plants was very insignificant in comparison with phosphates whose intensity depending upon the light conditions of the experiment.

WINOGRADOW's work (1957) explained that radioactivity of potassium does not play any role in the internal changes of plant organism, but much so its quantity and chemical properties.

In contrast to this abundance of data of potassium content in lake-and river-waters, information characterizing its occurence in pond-waters are rather inconspicuous. CZENSNY (1919) found in one of the experimental ponds of the Sachsenhausen fishery a potassium content between 1.33—2.77 mg/l K_2O. These relatively small quantities showed little difference from the quantities found in Wielenbach ponds (1.35 mg/l K) after a strong potassium manuring, which could certainly be attributed to bottom sorbtion. The highest quantities of potassium were found in ponds in autumn (supply of the drying vegetation). Ponds situated in high bogs were extremely poor in potassium (OHLE 1939) and potassium manuring in those cases (NOLTE 1931) produced specially good results. BREEST (1925) stated that loamy pond bottom assimilated quickly potassium from water. Considerable quantities of potassium were found in dry mass of some aquatic plants (*Vallisneria* till 5.48% K_2O, *Potamogeton*—2.08% K_2O).

One of the first attempts to estimate the rate of occurence and the role of potassium as an agent in production possibilities of a single breeding unit were the studies made in the years 1953/54 (STANGENBERG-OPOROWSKA 1961) upon the chemistry of water in some carp ponds near Milicz. The occurrence of potassium in all the investigated ponds, during one vegetative period was found to range from 1.5 till 8.8 mg/l K. The most frequent value being 2—4 mg/l K. Variability of content of this component in separate ponds, during a year was expressed by differences of the order of from 2.3 to 4.9 mg/l K. It has been stated that production results were by no means smaller in a fishery station Sławno that had at that time the smallest potassium content.

In the ponds of two experimental fishery stations of the Polish Academy of Sciences (PAN) in Gołysz and Landek, the potassium content were according to WRÓBEL's two papers (1962 and 1963) 1.2—3.3 mg/l K and in some other carp ponds of the Kielce Voivodship 1.9—6.6 mg/l K.

In order to investigate in a more complete way the rate and the variability of occurrence of potassium in polish pond waters, 8 chosen carp farms were, since 1962, submitted to a close study during the course of a whole year. The results thus obtained were supplemented by some data from 1953/54, as well from 1959 and 1961. The study tried to explain also what meaning may have for the production the smallest quantities of this component.

2. MATERIAL AND METHOD

Samples of water to determine the amount of potassium were taken twice, in spring 1962 (13.IV—28.V) and in late summer of the same year (20.VIII—7.X), belonging to 8 carp-breeding administrative units (Fig. 1), namely:

1. Modrzejowice (carp-farms: Modrzejowice, Wielgie, Bąkowa and Piastów, voivodship Kielce)
2. Skępe (carp-farm Chałacie, voivodship Bydgoszcz)
3. Charzykowo (carp-farm Kamienica, voivodship Bydgoszcz)
4. Łyszkowice (carp-farms: Łyszkowice, Walewice and Psary, voivodship Łódź)
5. Zator (carp-farm Poręba, voivodship Katowice)
6. Dębowiec (carp-farms Dębowiec and Kostkowice, voivodship Katowice)
7. Milicz (carp-farms: Milicz, Potasznia, Ruda Sułowska, Radziądz, Wierzchowice, voivodship Wrocław)
8. Slesin (carp-farm Slesin, voivodship Bydgoszcz).

Water was collected in quantities of 1.5 l with the aid of RUTTNER's dipper from the ponds near the discharge tube, some 20 cm below surface.

Altogether with the supplementary materials collected in the years 1953—1961 some 900 samples of water had been taken. These samples were analysed fully in order to know hydrochemical relations of polish pond water and their content in potassium which was determined with the aid of a Zeiss flame photometer.

3. POTASSIUM CONTENT IN POND WATERS

A. RANGE OF OCCURRENCE

Potassium content of 83 polish ponds (Table I) are discussed below. The 8 investigated fishery administrative units (Fig. 2) are presented in an order increasing quantities of potassium found in their ponds water. In 1962 these data were as follows:
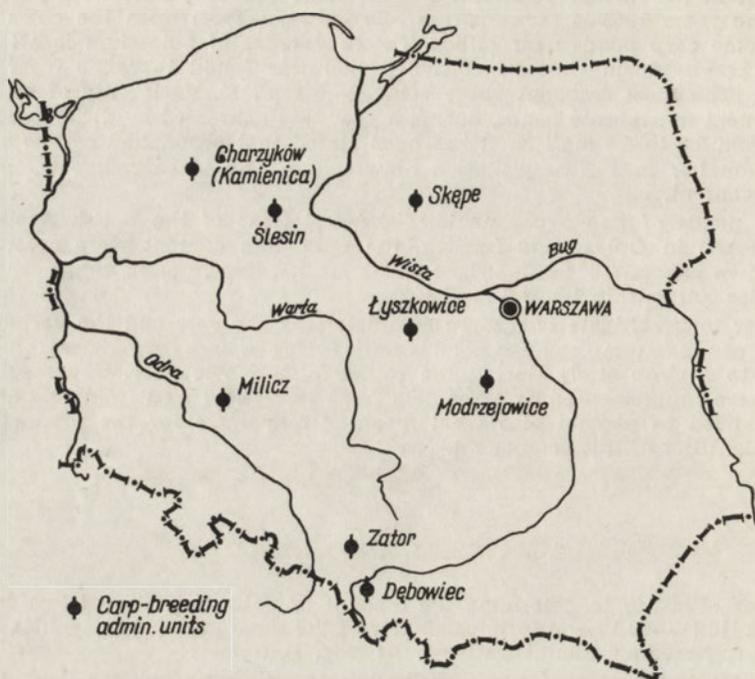
Fig. 1. Distribution of the examined ponds in carp farms, in which the determinations of potassium and sodium were made
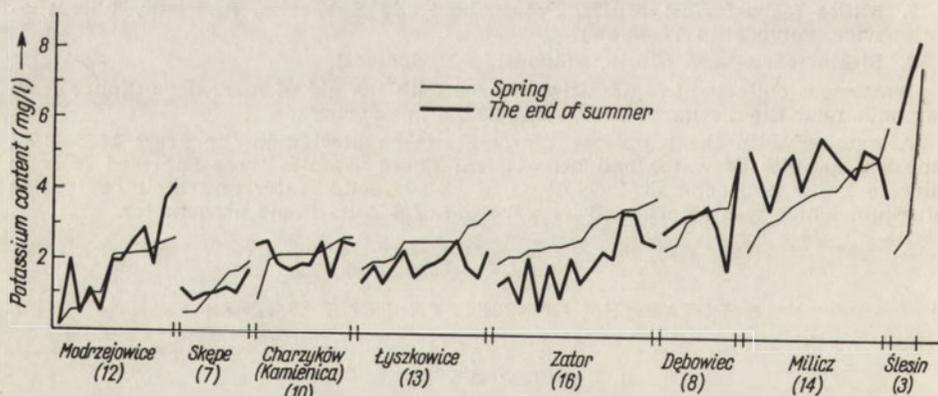

Fig. 2. Appearing of potassium in spring and by the end of summer in the water of ponds of Polish carp farms, 1962. Under the diagram: name of carp-farms and number of ponds

The range of fluctuations of potassium content in the pond water
of several groups of Polish carp farms in spring and by the end
of summer 1962

Name of the: Administrative Units	The Spring mg/l K	The end of Summer mg/l K
1. Modrzejowice	0.0–2.6	trace 4.1
2. Skępe	0.5–2.0	0.9–1.7
3. Charzyków (Kamienica)	0.9–2.7	1.6–2.6
4. Łyszkowice	1.8–3.5	1.4–2.6
5. Zator	2.0–3.7	0.9–3.5
6. Dębowiec	2.3–5.0	1,9–4.9
7. Milicz	2.3–6.0	2.4–6.6
8. Ślesin	2.5–7.6	6.1–8.5
Range of fluctuactions	0.0–7.6	trace– 8.5

a. Administrative Units where potassium content diminised in ponds
water at the end of summer

M o d r z e j o w i c e   U n i t,   v o i v o i d s h i p   K i e l c e. The characteristic
and common feature of nearly all ponds of this unit was the poor amount of
potassium found in them from 0.0 to 2.6 mg/l K in spring and trace to
4.1 mg/l K at the end of summer (Table I). The ponds situated on peat-bogs
and supplied mostly by rain water (e.g. Stary Młyn, Stara Jeruzel) showed
quantities of potassium approaching to analytical zero or very low (about
1.0 mg/l K).

In many of the investigated ponds of this unit (especially in the husbandry
Modrzejowice) the small amounts of potassium detected in spring, mostly
diminished at the end of summer, as seen from the list below, and from Fig. 2.

		Potassium content mg/1	
Name of carp–farm	Name of pond	4.V.62	5.IX.62
Modrzejowice	Gródki I	1.0	0.5
	Stary Młyn	0.0	traces
	Strugowa Olszyna	0.6	0.4
Piastów	Tama	2.1	2.0
	pond No. 5	2.0	2,0
	pond No. 6	2.4	1.9

The deficiency of potassium in the ponds of this unit could have in general
a diminishing influence upon the production of this husbandry unless autolytic
processes and a quick circulation of potassium in the metabolism of this pond
had not compensated the deficiency of this component.

S k ę p e   U n i t,   v o i v o d s h i p   B y d g o s z c z. Ponds of the husbandry
Chałacie belonging to this administrative unit were also characterized by a
poverty of potassium salts (table I, Fig. 2). In spring the amount of this

component did not exceed 2.0 mg/l K, with a range in the ponds of 0.5—2.0 mg/l K and towards end of the summer reached 0.9—1.7 mg/l K. Highest amount of potassium was found in the pond No. 5 as well in spring as by the end of summer. In the remaining ponds the potassium amounts were at the end of summer small and similar to each other.

C h a r z y k o w o - U n i t, v o i v o d s h i p B y d g o s z c z (l a k e - u n i t w i t h a c a r p - f r y i n g c e n t r e K a m i e n i c a). The husbandry Kamienica, hidden in woods of the voivodship Budgoszcz belongs to the ponds that are rather potassium poor. In the course of 1962 the occurrence range of this component in spring between 0.9 to 2.7 mg/l K, presenting little change towards the end of summer — 1.6—2.6 mg/l K (Table I). Ponds No. 10/2.7—2.6 mg/l K/ (and No. 11/2.7—2.5 mg/l K) were found to be richest in this component as well in spring as by the end of summer, pond No. 14 was the poorest in spring 0.9 mg/l K, while all the remaining ponds had at the beginning of the production period potassium contents only slightly above 2.0 mg/l K. Towards the end of summer these small potassium provisions diminished in most cases to the order of 1.6—1.9 mg/l K. Only 3 ponds (out of 10) showed at the end of the season an insignificant increase of potassium, one of the three ponds being the one that had the lowest content in spring (No. 14, Fig. 2).

Ł y s z k o w i c e U n i t, v o i v o d s h i p Ł ó d ź. The ponds of this administrative unit (Table I) during the whole season were characterized by potassium quantities below 3.0 mg/l K. Though in spring this component occurred in 1.8—3.5 mg/l K, only two of the 13 investigated ponds had an amount exceeding 3.0 mg/l K. By summer-end all the ponds had a pronounced decrease of potassium salts and their occurrence went down to the order of 1.4—2.6 mg/l K.

Waters of the carp-farm Psary (pond No. 13 and No. 31 from 2.3 till 3.5 mg/l K) appeared to have the richest potassium amount, while those of the Łyszkowice ponds had the porest quantity (1.4—2.1 mg/l K). A limiting role of potassium upon the production in most ponds of this complex seems highly probable.

b. Administrative Units in which the ponds water contained by the end of summer transitory amounts of potassium

Z a t o r U n i t, v o i v o d s h i p K a t o w i c e. More than a half of the 16 investigated ponds belonging to the carp-farm Poręba began their production in spring 1962 with potassium amounts between 2.0—2.7 mg/l K. The remaining ponds showed quantities above 3.0 mg/l K with a full range of oscillation between 2.0 to 3.7 mg/l K (Table I, Fig. 2). By the end of the production-period the content went down to 0.9—3.5 mg/l K in all the ponds maximal differences attaining 1.7 mg/l K (pond Sylwester).

On the whole it seems that many of these ponds did not dispose that year of a greater reserve of potassium salts.

D ę b o w i e c U n i t, v o i v o d s h i p K a t o w i c e. As it appears from table I greater amounts of potassium in spring pond-waters (2.3—5.0 mg/l K) diminished slightly only in some ponds by the end of the productive period, keeping at a level of 1.9—4.9 mg/l K. In spring maximal amounts of potassium (5.0 mg/l K) occurred in the pond Olszynny Wielki (Fig. 2), waters of the remaining ponds having a content between 2.3—3.7 mg/l K. The greatest

decrease of potassium salts was observed in the pond Nowy Wielki, where the difference between spring and autumn content reached 1.8 mg/l K.

From above given characteristics one may infer that in the ponds of this unit potassium had no limiting influence upon production.

c. Administrative Units where the potassium content had no decrease at the end of summer

M i l i c z U n i t, v o i v o d s h i p W r o c ł a w. In spring 1962 the potassium contents in Milicz ponds were between 2.3—6.0 mg/l K while by the end of the productive period they were 2.4—6.6 mg/l K (Table I, Fig. 2).

The only ponds in which the spring amounts of potassium decreased slightly at the end of the breeding season, were those of Ruda Sułowska. In all the remaining ponds of this unit the potassium content increased. In this respect the ponds of the complex Milicz differed distinctly from all the ponds belonging to the remaining complexes that we have characterized above.

The ponds Wierzchowice and Milicz had the greatest amounts of potassium salts (up to 6.6 mg/l K), those at Radziądz and Potasznia were characterized by smaller quantities (up to 5.7 mg/l K), and those of Ruda Sułowska showed the smallest quantity of this component (up. to 4.4 mg/l K).

Former investigations made on the Milicz ponds in 1953 showed spring amounts from 1.5 to 7.8 mg/l K and autumn quantities from 3.3 till 8.8 mg/l K. At a later period (1961) spring content was 2.1—7.0 mg/l K and that in autumn 2.3—7.4 mg/l K.

Ś l e s i n U n i t, v o i v o d s h i p B y d g o s z c z. As may be seen from table I, Fig. 2 in 1962 the highest amount of potassium was found in ponds of the husbandry Ślesin. This was 2.5—7.6 mg/l K in spring and by autumn time reached 6.1—8.5 mg/l K that is to say had a pronounced tendency to increase which may be attributed to the geological influence of watershed.

During the whole period of investigations the pond Kardynalski had a very rich amount of potassium-spring 7.6 mg/l K late summer 8.5 mg/l K. These figures were the highest amount of potassium of the whole material.

Summing up the results we can state that:

1. On the basis of the material from the years 1953/54 and the investigations up to 1962 and in 1962 the range of occurrence of potassium characteristic for the non polluted pond-waters in Poland is 0.0—8.8 mg/l K, to make even 0.0—9.0 mg/l K. All values above the maximum of this range may be derived from artificial pollutions. This stands in perfect accord with OHLMÜLLER-SPITTA's suggestions (1931) that all potassium contents in surface-waters greater than 8—9 mg/l K are to be regarded as being of sewage origin.

2. All ponds in Poland according to the amount of potassium found in their waters may be divided into 3 groups: a) Ponds poor in this component with a content lying mostly about 2.0 mg/l K or below that quantity (Table I, Fig. 2 — principally ponds of the units Modrzejowice, Skępe, Kamienica, Łyszkowice). This group showed to be pretty numerous: 34⁰/o of ponds under investigation. b) Ponds whose waters had medium contents of potassium (2—4 mg/l K) (e.g. many ponds in Zator, Dębowiec). This group is the most numerous making 52⁰/o of all the investigated ponds. c) Ponds with large

contents of potassium, above 4.0 mg/l K (Table I, Fig. 2), mostly Milicz and Ślesin, which make only 14% of the investigated ponds.

3. Towards the end of the productive period the potassium amount in the ponds poor in that component and belonging to the first group showed a further decrease in potassium; ponds rich in potassium showed its steady increase (Table I, Fig. 2 and Fig. 5-see below).

The above classification recalts the range of values established by OHLE (1939/40) for the lakes of eastern Hollstein-small amounts of potassium up to 2.0 mg/l K, medium : 2—3 mg/l K and large ones above 3.0 mg/l K. We feel inclined to regard decreasing quantities of potassium in a pond at the end of the productive period as an index of its deficiency. One can suppose on this basis, that this deficiency of potassium limited the production power of these ponds, and consequently quantities of potassium minor to 2.0 mg/l K may be regarded as small from the productive point of view and certainly require a supplementary potassium manuring.

B. FREQUENCY OF OCCURRENCE

The most frequent amounts of potassium found in all Polish ponds were 2—4 mg/l K (Fig. 3). During the ten years (1953, 1961, 1962) the most frequent amounts for the Milicz group with its many ponds (oftentimes investigated) were also equally 2—4 mg/l K and 4 to 6 mg/l K (Fig. 4).
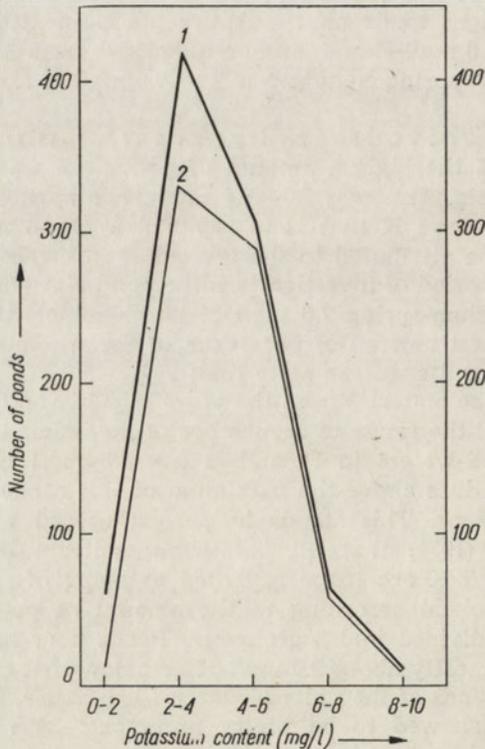

Fig. 3. Frequency of appearing of determined potassium contents in carp ponds of Poland

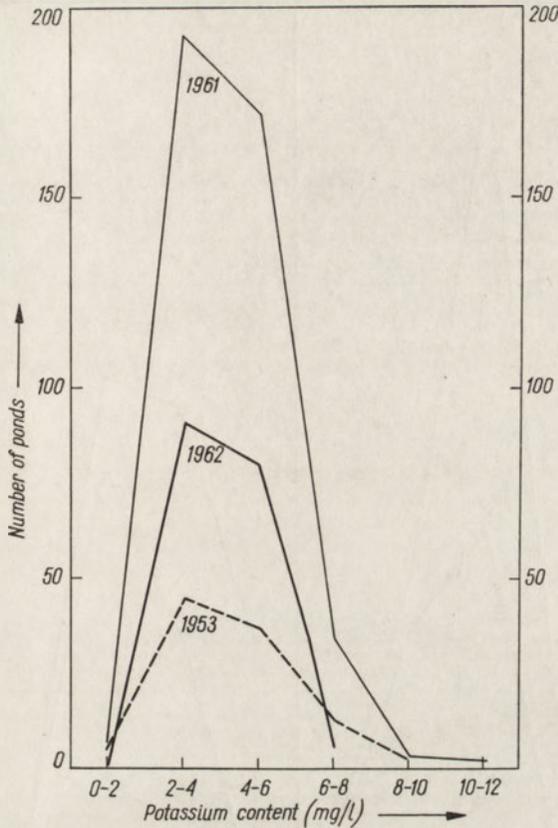1 — ponds of Poland; 2 — ponds of Milicz carp farm (1953—1962)

Fig. 4. Frequency of appearing of determined potassium contents in the pond water of Milicz-carp farm in three periods: 1953, 1961, and 1962

Grouping the samples into spring and late summer ones, one could state (Fig. 5) that potassium content of Polish ponds in their majority were in spring 2—4 mg/l K. This range remained characteristic also for the majority of Milicz ponds during spring.

At the end of the productive period the most frequent potassium contents (Fig. 5) characteristic for Polish ponds were as well 2—4 mg/l K as 4—6 mg/l K. At this occasion a group of ponds distinguished itself as poor in potassium, where the quantity of this component was below 2.0 mg/l K. As for the ponds of Milicz the most frequent range of occurrence was lying between 4—6 mg/l K. This seems to justify once more our division of ponds into "poor", "transitory" and "rich" in potassium, these latter suffering no diminution in late summer, but on the contrary showing an increase of potassium in water in connection with the masses of decaying plant and animal organisms as well as through evaporation, violent loss of water in ponds about that time and washing away of potassium from the bottom which emerges in many places or is covered only by very shallow water. As an example confirming the role of evaporation and violent supply of potassium from decaying plant remains I should like to cite relations found by me in one of the investigated astatic basins near
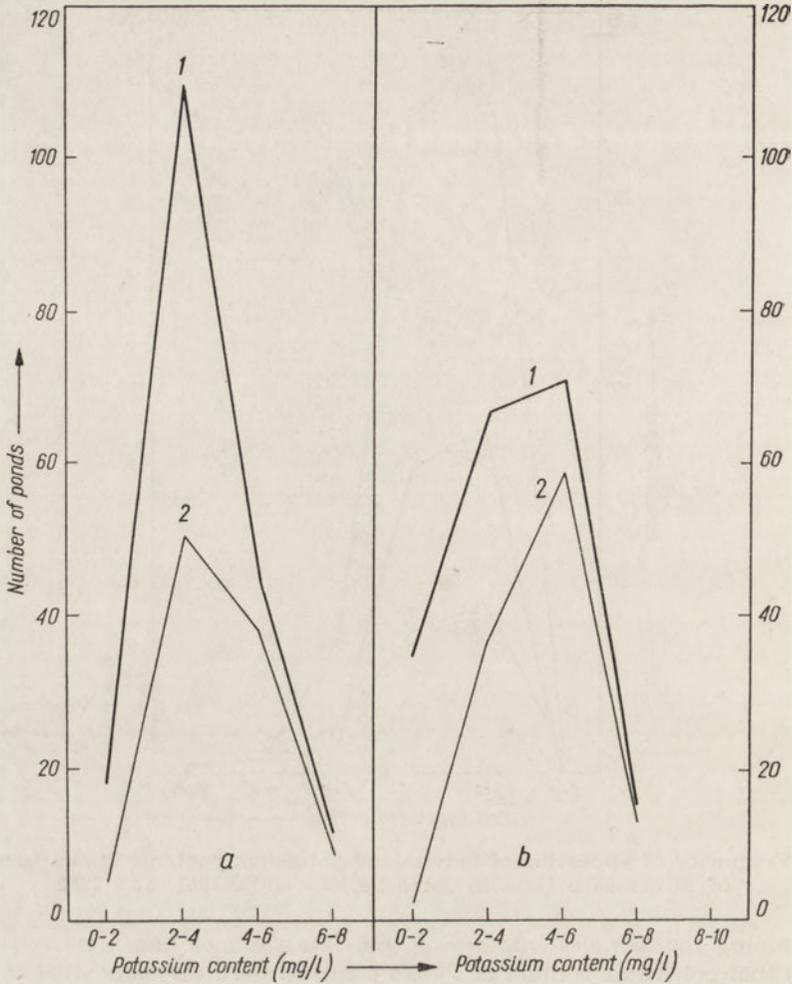
Fig. 5. Frequency of appearing of potassium contents in the pond water in depend-
ance on the season

1 — Carp farms of Poland, 2 — Milicz-carp farm a — spring, b — the end of summer

Zaborów (environs of Warsaw) where potassium increased nearly five times
to its former content, between the middle of April 1955 and middle of June
of the same year:

Date	Potassium, mg/l K
14.IV	8.5
28.IV	9.5
12.V	12.5
25.V	12.0
10.VI	14.7
22.VI	40.5

Table II

Potassium contents in the pond water of the Milicz-unit, 1961/mg (l)

Pondfarm: Milicz

Pond	3. V.	16. V.	30. V.	14. VI.	6. VII.	17. VII.	17. VIII.	31. VIII.	21. IX.	Range of fluctuations
Wilczy Duży	3.2	3.5	3.3	3.0	3.8	3.8	1.7	4.1	4.8	1.7—4.8
Bolko I	3.2	3.5	3.3	2.8	3.8	2.8	2.0	3.9	4.5	2.0—4.5
Bolko II	3.7	4.5	4.3	3.5	3.0	3.8	—	3.9	4.3	3.0—4.5
Gadzinowy Duży	3.0	—	3.1	2.6	3.0	4.6	2.0	4.6	—	2.0—4.6
Staś Górny	4.0	4.5	3.1	2.8	3.5	3.8	2.2	4.5	5.2	2.2—5.2
Machnicki Górny	4.5	4.7	5.0	4.3	4.5	4.5	2.2	—	2.5	2.2—5.0
Słowian	3.3	3.3	3.1	3.3	4.1	4.3	2.3	—	3.5	2.3—4.3
Wilczy Mały	3.0	3.2	2.6	2.5	3.2	3.5	2.5	3.8	—	2.5—3.8
Machnicki Dolny	3.3	3.8	3.6	3.5	4.5	5.3	2.8	—	—	2.8—5.3
Słoneczny	3.1	3.3	3.1	2.8	3.3	3.8	2.8	5.3	5.8	2.8—5.8
Leszek	7.0	6.3	3.1	3.6	3.5	4.5	3.0	3.2	4.0	3.0—7.0
Henryk	4.5	4.5	4.8	3.8	5.3	5.3	3.0	3.2	—	3.0—5.3
Przelotny	3.0	—	2.8	2.6	3.3	5.5	3.2	4.7	5.1	2.6—5.5
Staś Dolny	3.6	3.8	3.5	3.2	3.2	3.5	3.2	3.5	4.1	3.2—4.1
Mieszko	4.2	4.2	4.5	3.5	4.3	4.6	3.5	4.1	4.6	3.5—4.6
Grabownica	3.9	4.6	4.5	4.1	4.1	4.3	4.0	4.3	5.0	3.9—5.0
Golice	4.5	4.6	4.6	4.6	5.3	5.7	4.1	6.5	7.0	4.1—7.0
Polny	4.7	5.4	6.0	5.7	8.0	6.3	5.3	6.5	6.9	4.7—8.0

Pondfarm : Wierzchowice

Pond	12. V.	26. V.	15. VI.	29. VI.	13. VII.	10. VIII.	24. VIII.	7. IX.	Range of fluctuations
Antoni	4.7	5.1	3.5	3.0	2.3	1.7	—	2.3	1.7—5.1
Duża Przystań	4.6	4.7	4.1	4.1	4.5	2.3	4,8	5.3	2.3—5.3
Lipsk	6.0	4.8	5.4	6.5	5.4	2.5	4,7	4.7	2.5—6.5
Tatarak	4.5	—	4.3	3.8	2.0	2.5	—	—	2.0—4.5
Emilia	3.9	4.0	4.6	4.6	5.1	3,0	6.2	—	3.0—6.2
Ernest	2.1	2.4	3.0	3.1	2.6	—	2.6	—	2.1—3.1
Karol Duży	5.5	4.8	4.1	4.3	4.7	3.0	4.5	4.5	3.0—5.5
Henryk Górny	4.5	5.7	4.3	4.5	4.6	3.0	4.7	5.3	3.0—5.7
Mały Karol	5.0	4.6	4.1	4.1	3.6	3.1	4.6	4.5	3.1—5.0
Nowy	5.5	5.5	5.3	5.7	5.5	3.5	6.2	6.2	3.5—6.2
Czarny Las	5.0	5.7	4.7	5.1	4.6	3.5	4.8	4.8	3.5—5.7
Mała Przystań	4.6	4.6	4.1	4.5	4.6	3.5	5.0	5.3	3.5—5.3
Henryk Duży	4.7	4.6	4.5	4.3	3.8	3.6	—	7.4	3.6—7.4
Karol Dolny	3.8	—	7.0	5.0	4.7	4.1	5.3	5.4	3.8—7.0
Duży Wrzosowiec	4.5	4.6	4.7	4.7	5.3	3.6	5.1	5.3	3.6—5.3
Graniczny	6.2	6.0	6.0	6.3	5.5	4.1	—	4.6	4.1—6.3
Chełm	2.7	2.8	2.3	2.3	3.3	4.7	3.5	3.8	2.3—4.7

Tab. II. c.d.

Pondfarm: Potasznia

Pond	8. V.	23. V.	5. VI.	19. VI.	6. VII.	30. VIII.	Range of fluctuations
Jasny Dolny	3.2	2.6	2.3	2.3	4.5	1.5	1.5—4.5
Jasny Górny	3.5	3.0	3.0	2.3	4.6	—	2.3—4.6
Gądkowicki	6.8	5.4	5.0	4.3	6.7	2.8	2.8—6.8
Kaczy	3.2	2.4	3.2	3.3	6.7	3.1	2.4—6.7
Jan	4.2	3.0	2.8	2.6	8.0	2.9	2.6—8.0
Górnik	4.0	5.0	5.0	6.2	6.8	4.6	4.0—6.8
Brzesławicki	6.0	5.7	5.3	4.7	—	6.0	4.7—6.0
Murzyn	6.1	4.7	4.1	—	6.7	—	4.1—6.7

Pondfarm: Radziądz

Pond	8. V.	23. V.	5. VI.	19. VI.	6. VII.	17. VII.	14. VIII.	30. VIII.	11. IX.	Range of fluctuations
Jeleni I	3.5	3.5	3.6	3.1	3.3	3.8	1.7	—	4.5	1.7—4.5
Jeleni II	3.5	3.5	3.2	3.2	3.0	—	2.6	—	3.5	2.6—3.5
Jeleni III	3.8	2.6	4.6	3.5	4.5	3.6	4.5	4.3	4.6	2.6—4.6
Stary	3.8	4.6	3.9	3.1	3.5	3.8	—	4.1	4.5	3.1—4.6

Pondfarm: Ruda Sułowska

Pond	16. V	21. V	30. V	5. VI	19. VI	5. VII	17. VII	14. VIII	28. VIII	11. IX	Range of fluctuations
Żabieniec	3.2	2.0	2.4	2.6	2.3	1.7	3.1	1.2	2.3	3.0	1.2—3.2
Grabówka	5.0	—	5.0	4.5	4.7	3.3	7.0	3.0	6.3	6.0	3.0—7.0
Mewi Mały	4.0	4.3	4.7	3.8	3.6	4.7	5.0	3.2	4.8	4.7	3.2—5.0
Mewi Duży	3.8	4.1	4.3	4.1	4.1	3.3	4.5	3.2	—	4.6	3.2—4.6

C. CHANGES OF POTASSIUM CONTENT IN POND WATER DURING VEGETATION PERIOD

Tests for potassium contents made once or twice every month in 1961 on 51 ponds in Milicz showed (Table II) that during vegetation period the quantities of this component in the water of all ponds oscillated between 1.2—8.0 mg/l K. These extreme quantities appeared in the course of the vegetative period neither in spring nor autumn. This fact alone shows that potassium content in some ponds may undergo far-reaching changes both decreasing and increasing in proportion to the composition of the flooding water.

On analysing closely the ciphers in table II we see that during the vegetative period the waters of many ponds had two minima of potassium: one mid-June and another mid-August, which seems to be connected clearly with the growing of plants in ponds about that time. These two periods are contemporary also with two maxima of primary production in ponds (WINBERG 1960).

The June and August potassium minima were often divided by a more conspicuous increase of potassium content of 1 mg/l K or even more, as for instance in the ponds Wilczy Mały, Gadzinowy Duży, Słoneczny, Staś Górny and many others. Sometimes, in August, water happened to have specially large quantities of potassium as for instance in the pond Chełm — 4.7 mg/l K. This increase may easily be explained by potassium having been washed away from dying plants, its supply from the bottom and by evaporation of water.

Changes between the maximal and the minimal values for one pond during one season only once attained 5.1 mg/l K, being most of time much smaller to a last order of 0.7 mg/l K.

Earlier described changes (OPOROWSKA 1961) of potassium content in the ponds Grabownica and Duża Przystań (in 1953) during one vegetation period were from 2.2 mg/l K to 4.4 mg/l K, that is to say rather strong and similar to changes given above in the materials of the year 1961. This order of change between maximal and minimal values in occurres separate years through the whole period of 10 years of investigation:

Pond Grabowica (Milicz)

| Year | Potassium content during vegetative period (mg/l K) | | |
	minim-um	maxim-um	difference
1953	2.3	6.7	4.4
1954	2.3	5.0	2.7
1961	3.9	5.0	1.1
1962	2.2	4.8	2.6

Pond Duża Przystań (Wierzchowice)

| Year | Potassium content during vegetative period (mg/l K) | | |
	minim-um	maxim-um	difference
1953	5.2	7.4	2.2
1954	4.4	7.7	3.3
1959	4.8	7.2	2.5
1961	4.1	6.2	2.1
1962	3.5	5.1	1.6

In other potassium rich ponds of Poland the variability of K content during the vegetative season is rather a great one, about 5.0 mg/l K and lying most frequently below 3 mg/l K. Moreover that the potassium quantities are rather constant over of many years within the same pond, despite this great seasonal variation. Where greater deviations fluctuations occure these may have some special cause (manuring, feeding, plant leaching, pollutions). That afford a special explanation.

4. MINIMUM AMOUNTS OF POTASSIUM HAVING A LIMITING POND INFLUENCE UPON PRODUCTIVITY

Earlier suggestions in fisheries (DEMOLL 1925) about the limiting influence of lack of potassium might have upon carp production in pond-waters, have not yet been tested experimentally.

Older investigations made by ZUNTZ and KNAUTHE (1901) from this point of view, were, unable to determine either optimal doses of potassium required or least quantities that may check the production. Among other reasons it was so because concentrations of potassium used in breeding exceeded considerably the amounts existing in pond waters. Attempts made later by others, also did not bring any results in this respect, while RHODE's work (1948)

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on the contrary demonstrated that even such small amounts of potassium as 0.2—1.0 mg/l K did not have a checking influence upon development of *Scenedesmus quadricauda* in laboratory breeding.

The opinion that a relatively high productivity of a water basin having an actual low potassium content may be possible in view of the fact that assimilating of potassium through plants and its liberating from dead plant tissue go on quickly, and that there exists in the basin a stock of "circulatory" potassium, which takes part in the production so to say "in statu nascendi" is now more and more widely accepted.

The things being even so, the question arises, whether the carp-production in a pond is not to some degree dependent upon the amount of this "circulating capital" of potassium existing in the given pond. Ciphers cited above demonstrated that potassium quantities found in pond waters showed sometimes sensible differences.

Comparison of carp production in Polish ponds with actual amounts of potassium found in them did not confirm the existence of any such correlation. Although NEMEC and FASTROVA (1941) affirm that in Czechoslovakian ponds carp production grew distinctly with growing potassium amount in water. The table given by these authors is not free of certain inconsequencies and exceptions, to say nothing of the fact that potassium amounts found in Czechoslovakian ponds were several times repeatedly superior to the amounts we have stated in Polish ponds or other authors in different European waters.

Compering together the smallest amounts of potassium found by various authors in European lakes of low productive efficiency we see (compare bibliography in introduction) that they were everywhere less than 1.65 mg/l K and sometimes even less than 1.0 mg/l K. THOMAS (1949) found in productively poor dystrophic. Swiss lakes amounts minor to 1.5 mg/l K, or even of the order of 0.7—0.8 mg/l K. Similary in surface waters of dystrofic lakes of Poland the potassium amounts were below 0.5 mg/l K (Suchar Zachodni-0.25 mg/l K, Suchar III-0.5 mg/l K). The productively poor lake "Leśne" (district of Sztum) in the layers 0—10 m had a potassium content in spring 1958 only 0.4 mg/l K (own investigation). Smallest amounts of potassium found in forest-lakes of Schleswig-Holstein by OHLE (1939) were 1.3—1.9 mg/l K and HÖLL (1951) based on his 15 years of study upon the potassium content in surface waters comes to the conclusion that only quantities below 1.0 mg/l K may in some degree have a limiting influence upon the productivity of the lakes, wheares quantities of the order 1—2 mg/l K are sufficient to make the production rather high. German "Landesanstalt für Fischerei Friedrichshagen" alone presents amounts below 2.0 mg/l K as limiting pond production. To sum up, it seems that a water-basin that had potassium content below 1 mg/l K never developed a more serious fish production and even at quantities of 1—2 mg/l K such production could not develop.

If the medium natural efficiency of carp-ponds in Poland is about 100 kg/ha of carp it signifies that every year every hectar of pond is deprived of 20 kg of potassium which by 1 m of water depth corresponds to 2 mg/l K. That is just as much as we most often find in the majority of Polish ponds. These quantities must return every year to the pond, therefore it appears probable that potassium quantities below 2 mg/l K are constantly in danger of being exhausted by the actual fish production of the pond. With a potassium content greater than 2 mg/l K this danger diminishes.

In the above presented investigations we have drawn attention to the fact that in Poland there is a pretty large group of ponds (34%) with a potassium content below 2 mg/l K, in which this component shows a regular decrease towards the end of the vegetative period, despite the cyclic liberation of potassium from plant and animal organisms we have already spoken of. As it appears this decrease of potassium results from its fixation in fishes and from its lack in the bottom or other elements of the pond, from where it could be supplied. This seems to show, in accordance with quotations from literature we have given above, that quantities of potassium below 2.0 mg/l K during the whole productive period, in a carp pond, are an index of its poverty in potassium, its power of limiting production and a hint to the necessity of completing thet deficiency by manuring. Quantities above 2.0 mg/l K may have different significance in correspondence with the level of production. That is again formed in dependence upon others factors that determine the production.

All we have said seems to be confirmed in a high degree by the fishery practice, that potassium manuring of the ponds does not always help to raise their efficiency. None the less potassium manuring have given in some cases fairly good results. Demoll and Maier could demonstrate that 1 kg of K_2O gave a weight-growth of 0.24—1.27 kg of carp, and Brüning (1930) obtained in the ponds of Racibórz even as much as 2.38 kg of fish weight from each 1 kg K_2O 40% potassium salt. These data point to an extremely varied effect of manuring in ponds. Such manuring, as we can suppose will be especially efficacious in those ponds whose waters have shown during our investigations at the end of the production period a decrease of potassium. Ponds of this kind make in Poland at least 50% of the whole number.

To sum up our results we feel sure that potassium quantities below 1.0 mg/l K have a limiting influence upon the production. Contents of this component within 1.0—2.0 mg/l K may have a limiting influence only in some cases, while those abowe 2.0 mg/l K have no limiting influence upon average carp production of polish ponds.

5. SUMMARY

Basing on 900 water samples taken from different ponds of Polish carp farms in the years 1953—1962 (Fig. 1) and potassium determinations made in them by means of Zeiss flame photometer, it has been found that:

1. Potassium contents found in inpolluted water of Polish ponds are contained within the range 0.0—9.0 mg/l K (Table I, Fig. 2), all higher values being probably of pollution descent.

2. The quantities of potassium which are most frequently found in the water of Polish ponds are those contained within the limits 2—4 mg/l K. (Fig. 3 a. 4). There has been distinguished the group of ponds with „poor" water (0.0—2.0 mg/l K), „moderately affluent" (2.0—4.0 mg/l K) and „rich" (above 4.0 mg/l K) in potassium, what corresponds to 34%, 52% and 14% of all the examined ponds.

3. Ponds „poor" and even „moderately affluent" in potassium generally showed a loss of this component by the end of the production period, while in the ponds „rich" in potassium its content was most frequently found to increase by the end of the production period (Fig. 5.).

4. There was proved appearing of two minima of potassium (June, mid-August) in the pond water during the production season (Table II), which seems to be connected with two periods of growing of plants in ponds about that time.

5. In two ponds (Grabownica, Duża Przystań) the potassium varied considerably seasonally but remained at much the same level throughout a 10-year period.

6. As in many farms ponds „poor" in potasium salts boasted a more consider-
able production of carp, it seems necessary to revise the view concerning the con-
tent of this component in pond water. It seems that quantities below 2.0 mg/l K may
be regarded as limiting the production of phytoplankton in pond water.

6. STRESZCZENIE

Na podstawie pobranych 900 prób wody z różnych stawów gospodarstw karpio-
wych Polski w latach 1953—1962 (fig. 1) i oznaczenia w nich potasu przy pomocy
fotometru płomieniowego Zeissa stwierdzono:

1. Zawartości potasu występujące w nie zanieczyszczonych wodach stawów Pol-
ski leżą w zakresie 0,0—9,0 mg/l K (tab. I., fig. 2), a wszystkie wartości wyższe są
zapewne pochodzenia zanieczyszczeniowego.

2. W wodach stawów Polski najczęściej spotyka się ilości potasu leżące w gra-
nicach 2—4 mg/l K (fig. 3 i 4). Wyróżniono grupę stawów o wodzie „ubogiej" (0,0—2,0
mg/l K), „średnio zasobnej" (2,0—4,0 mg/l K) i „bogatej" (powyżej 4,0 mg/l K) w potas,
co stanowiło 34, 52 i 14% badanych stawów.

3. Stawy „ubogie" a nawet „średnio zasobne" w potas wykazywały na ogół uby-
tek tego składnika pod koniec okresu produkcyjnego, natomiast w stawach z grupy
„bogatej" w potas stwierdzano najczęściej wzrost jego ilości pod koniec okresu pro-
dukcyjnego (fig. 5).

4. Wykazano występowanie dwu minimów potasu (czerwiec, połowa sierpnia)
w wodzie stawowej w ciągu sezonu produkcyjnego (tab. II), co zdaje się wiązać
z dwoma okresami narastania produkcji roślinnej przypadającymi właśnie w tych
okresach.

5. Na przykładzie 2 stawów (Grabownica, Duża Przystań) stwierdzono występo-
wanie dość znacznej zmienności sezonowej potasu przy tendencji do utrzymywania
się podobnego rzędu różnic między wartościami maksymalnymi a minimalnymi
w ciągu dłuższego jak wykazano, 10-letniego okresu.

6. Ponieważ stawy wielu gospodarstw, ubogie w sole potasowe, wykazywały
jednocześnie znaczniejszą produkcję karpia, wydaje się konieczne zrewidowanie
poglądu na najmniejsze, limitujące produkcję fitoplanktonu, zawartości tego skład-
nika w wodzie stawowej. W warunkach stawów Polski za takie uważać można za-
wartości poniżej 2,0 mg/l K.

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LIMNOLOGICAL INDIVIDUALITY OF SMALL LACUSTRINE BAYS

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ABSTRACT

A degree of the individuality of the bay water masses has been investigated, with the differences in the chlorophyll content and in the turbidity also analyzed. Small bays may keep their individuality which, however, is sometimes disturbed by stronger winds that cause mixing of water masses. In most cases, smaller amounts of chlorophyll have been recorded in the bay than in the central basin.

CONTENTS

1. INTRODUCTION

Different water masses, having their own individual properties may be met with within the limits of one lake. Stangenberg (1935) stated that, in contradistinction to relatively oligotrophic central basin of Lake Wigry, its bays are, depending on the depth, either eutrophic, or pondlike in character. Analyzing the distribution of planktonic crustaceans in Lake Wigry, Koźmiński (1932) observed in its bays the occurrence of species different from those, recorded in the central basin of this lake. During his studies on chemical properties of Lake Tajty, Olszewski (1953) found that the central basin, called ploso Wrońskie, displayed a lower degree of eutrophization than that, called Tajty Długie.

An analysis of selected indexes of the limnological individuality of small lacustrine bays, that is, chlorophyll and seston content of water, is the aim of this paper. The author tried to collect data on the degree of turbulence (or tranquility) of water in the bays investigated and to appraise the extent to which water masses of the bays are affected by the influence of the water from the central basin of the lake which they adjoin.

The morphometric properties of bays, determining the extent of their isolation, concern the size of a bay and the size of a zone in which bays and main basins of the lake contact each other. The bigger the water mass of a bay and the smaller the cross section through its boundary area, the greater should be the degree of its isolation.

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The mobility of the bay water masses is decreased by higher aquatic vegetation, developing on bay shores and, in the case of shallow bays, also on the bottom. This vegetation slows down drift currents and, consequently, decreases the effects of the wind action thus increasing the degree of the isolation of the bay. It is particularly the emerged vegetation, developing in the boundary area, that effectively isolates the bay from the main part of the lake.

The mobility of waters of the main basin of the lake close to the bay (currents and waving), resulting from the action of winds, reduces or even destroys the limnological individuality of bays. Many phenomena, physical in character, such as, currents, waving, turbulent mixing of water and changes in the water level are caused in this environment by the wind.

According to KARAUŠEV (1961), the lacustrine currents may be divided into a) flow currents, b) drift currents, c) gradient currents and d) longshore currents, running along the shores.

In the present paper, I have analyzed one of the phenomena mentioned above, namely, waving or, strictly speaking, mixing of water masses as a result of waving, as well as one type of current — a drift current which causes the displacement of superficial water masses.

I would like to express my gratitude to Professor J. MIKULSKI, Professor K. PETRUSEWICZ and Docent K. PATALAS for their help and valuable remarks on this paper, as well as to all other persons to whom I am indebted for their help.

2. METHODS

To cut down the descriptions of particular bays, the following definitions and terms have been introduced (Fig. 1):

a) The s h o r e s of the bay: a shore to the left side of the beholder, facing the lake from the bay, is called the left shore. The right shore is defined according to this same principle.

b) The e n d of the bay: a part of the bay which makes up the deepest indentation of the shore.

c) The b o u n d a r y of the bay: a line, connecting the sections of the left and right shore of the bay which, to the greatest extent, reach towards the lake basin.

d) The m e d i a n l i n e: a line, connecting the central point of the end of the bay with the center of the boundary of the bay and running at equal distance from both shores of the bay.

e) The a x i s of the bay: a straight line, connecting the central point of the end of the bay with the center of the boundary of the bay.

f) The p r o m o n t o r y: a place in which the shore of the bay passes into the shore of the central basin of the lake or, this is a part of the bay shore most extended towards the central basin.

The median line almost completely coincided with the axis of the bay investigated.

To determine the differences between the water of the bay and that of the central basin, a series of samples was taken, beginning with the end of the bay, along its axis up to its boundary and, another series — in the central basin — in the continuation of the bay axis. Then, the mean values of a series of the chlorophyll content and the turbidity of water were calculated for the bay and for the central basin. The differences in the chlorophyll content and in the turbidity indicated the individuality of the waters, sampled from the bay and from the central basin.

Samples were taken from the surface of water. A series from one bay contained 18 to 22 samples. To exclude the possibility of the influence of the diurnal variation, water was sampled only in the afternoon hours. A total of about 500 samples were taken for the chlorophyll test and about 500 for the analysis of the optical properties of water. Samples were taken in 1960 during the vegetation period.

The turbidity of water was determined nephelometrically by means of the Pulfrich nephelometer. KREY (1952) was the first to apply this method to the analysis of water masses. The magnitude of the TYNDALL effect, determined by the photometer, was converted into the units of „absolute turbidity" according to the indications of the Zeiss-Jena Comp. The application of the unit of „absolute turbidity" allows one to compare the results, obtained by different investigators who use nephelometers of different types.

A method introduced to limnology by KOŹMIŃSKI (1938), consisting in the determination of the chlorophyll content of a unit of water, was applied to the analysis of the quantities of phytoplankton. One liter of water was taken to determine the chlorophyll content. The samples were fixed with chloroform in the quantity of 1 ml per 1 liter of water which was forced through hard paper filters. To deactivate the chlorophyllase, the filters were placed for 45 sec under the steam jet (KREY 1939) then, put into a flask and poured over with the extraction liquid (95% ethanol, denatured with methanol). The extraction was carried out three times, each of them lasted for 24 hours. Successive extracts were poured together. The suspensions were removed from the sample by means of the centrifugel force (600 r.p.m. for 15 minutes). The supernatant was refilled to 25 ml with a pure extraction liquid. The extinction was measured by means of the Pulfrich photometer and with the application of micro-tubes 20 cm long. A pure solvent was used for compensation. The S. 66/665 mμ filter was used for measurements. The „chlorophyll a", made by Sandoz Comp. was applied to the calibration of the photometer.

3. TERRAIN DESCRIPTION

The investigations were carried out in the vicinities of Mikołajki in 5 bays of lakes Mikołajskie, Tałtowisko and Bełdany.

According to a generally accepted definition, a bay is an inlet in the shore of a sea or lake. If the area of the bay, compared with that of the central basin is not large, there are no difficulties in determining whether or not a given inlet in the shore is a bay. When, however, the area of the inlet in the shore under study approaches in size the area of the adjoining central basin, then, the question arises if we still have to do with a bay or with another, but smaller, basin of this lake.

LAKE MIKOŁAJSKIE

Lake Mikołajskie with a clinograde oxygen curve (SZCZEPAŃSKI 1958) has an area of 470 ha and a maximum depth of 27.5 m. The shores of the lake are mostly high and, in the western part, almost completely overgrown with forest. The Kobyliniec — M₁ bay of this lake has been investigated (Fig. 2).
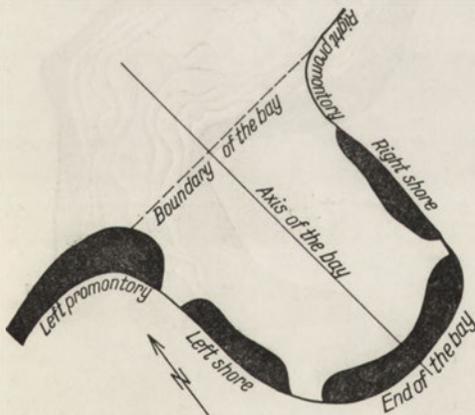
Fig. 1. Configuration of an bay
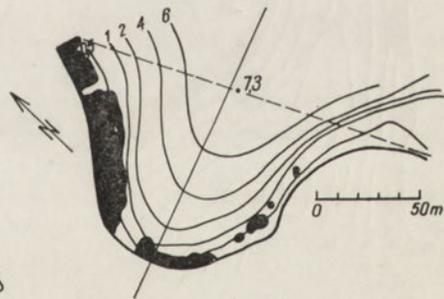
Fig. 2. Bathymetric map of the M₁ bay (Kobyliniec) of the Lake Mikołajskie

The M₁ bay is situated on the western shore of the lake. Its shores are high and overgrown with leafy and mixed woods. A belt of *Phragmites communis* TRIN. 20 m. wide with boggy coastal parts runs along the left shore. The right shore is almost completely devoid of aquatic plants except for small clumps of *Phragmites communis* TRIN. and *Sagittaria sagittifolia* L. Near the right-hand promontory, the bottom,
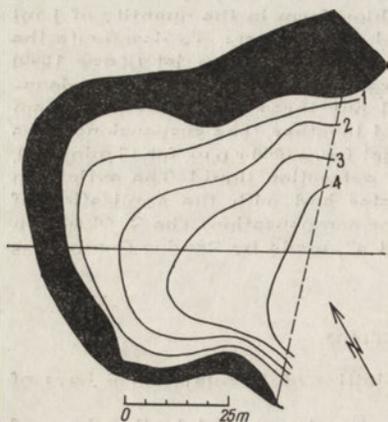
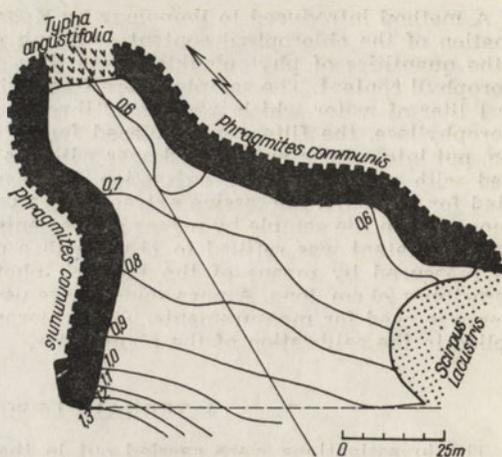Fig. 3. Bathymetric map of the T_1 bay of the Lake Tałtowisko

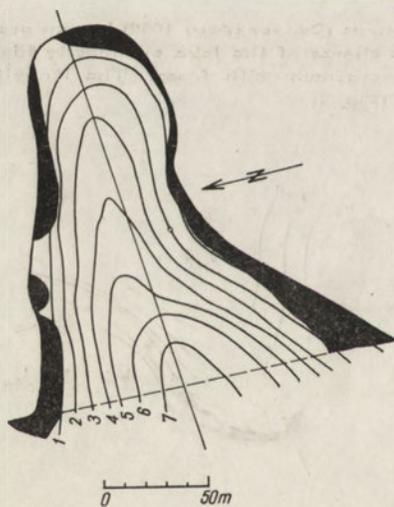Fig. 4. Bathymetric map of the T_2 indentation in reeds of the Lake Tałtowsko

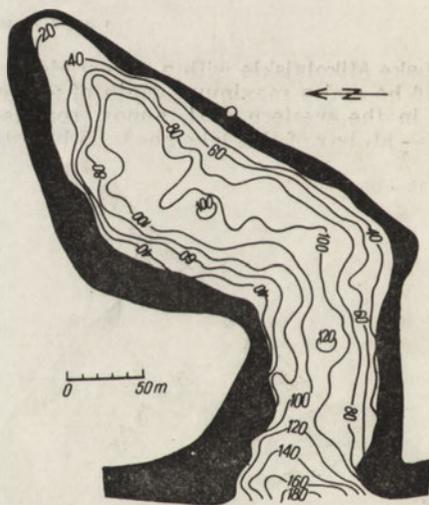Fig. 5. Bathymetric map of the B_1 bay of the Lake Bełdany

Fig. 6. Bathymetric map of the B_2 bay of the Lake Bełdany

covered with sand and stones, is characteristic of a littoral, exposed to the action of waves. The end of the bay is overgrown with *Phragmites communis* TRIN., *Carex* sp. and *Nuphar luteum* (L.). Towards the center of the bay, the bottom becomes boggy, loamy-sandy, sandy and, in some parts, overgrown with the meadows of *Elodea canadensis* RICH. A maximum depth of the bay amounts to 7.3 m. The M_1 bay is

screened from the south by a big clump of emergent plants. This clump is set back some scores of meters from the right shore of the bay and reaches far towards the center of the lake. It makes up an effective screen against the influence of waves, running from the SSE.

LAKE TAŁTOWISKO

Lake Tałtowisko is reckoned among the lakes of the mesotrophic type (OLSZEWSKI, PASCHALSKI 1954). Its area amounts to 326.9 ha and maximum depth — to 39.5 m. A cliff, reaching a height of 10 m. above the lake level and, northwards, becoming ever lower, runs south-eastwards along the shore. This cliff is situated a dozen or so meters from the shore line. The north-east bank, overgrown with forest, is boggy and wet. A steep slope, also overgrown with forest and dominating the lake level by 10 m., runs at a distance, varying from 50 to 200 m. The south-eastern and south-western shores are low and devoid of a forest cover. Lake Tałtowisko is connected with other, adjoining lakes by canals. A belt of emergent plants which, in the southern part, occupies a very large area, surrounds the lake. In the southern part of the lake, the belt of emergent plants is not continuous and forms indentations and eyelets different in size. On this lake, the investigations were carried out in the T_1 bay and in the T_2 indentation in the reed.

The T_1 bay (Fig. 3) is situated in the terminal section of the northern, narrowed part of the lake. The axis of the bay is more or less perpendicular to the axis of the lake. The entire bay is bordered with a belt of *Phragmites communis* TRIN. and its terminal part is overgrown with *Nuphar luteum* (L.). *Fontinalis* sp. occurs on the borderline between the water and land. The bottom of the bay is loamy with a considerable amount of organic remains. The shores of the bay are relatively low. The entire bay is surrounded by fields under crop. A maximum depth of the bay amounts to 4 m.

The T_2 indentation (Fig. 4). Since the borderline of the reed covered area is irregular and forms different bends and curves, frequently screened by adjacent reed covered areas from the direct contact with the open lake, a question arises to what an extent the reed covered areas play their screening role and to what an extent the indentations in these areas may, in their properties, approach the bays. The T_2 indentation is situated in the central basin of the lake on ist eastern shore. The right-hand shore of the T_2 indentation is densely covered with reed. The left-hand shore is partially overgrown with the reeds *Phragmites communis* TRIN. and partially with a clump of *Scirpus lacustris* L. The end of the T_2 indentation is bordered by the *Typha angustifolia* L. The shore of the lake in the vicinity of the T_2 indentation is low, wet and overgrown with forest. The bottom of the T_2 identation is sandy with a small amount of organic remains. The depth is small, from 60 cm and less in terminal parts to 130 cm close to the boundary. Of the immersed vegetation, *Potamogeton lucens* L. occurs on the boundary between the indentation and the central part of the lake. However, it does not form dense communities and its single specimens occur at fairly large intervals.

LAKE BEŁDANY

Lake Bełdany makes up a southern extension of Lake Mikołajskie. Its area amounts to 780 ha and maximum depth (measured by the author) — to 47 m. The lake is narrow and its high shores, covered with forest, considerably moderate the influence of the wind. Lake Bełdany is reckoned by OLSZEWSKI and PASCHALSKI (1959) among the eutrophic lakes. On this lake, the investigations have been carried out in two bays.

The B_1 bay (Fig. 5) is situated on the eastern shore of the lake, about 1 km from the sluice at Guzianka. The shores of the bay are high and covered with a mixed forest. The belt of reeds is narrow and with many gaps. The reeds are rather low and sparse, except for a promontory on the right-hand margin of this area where they are more exuberant and dense. The bottom of the terminal section of the bay is boggy, loamy-sandy and loamy with a large amount of organic remains. In the deeper parts of the bay, the bottom is overgrown with *Elodea canadesis* RICH. Close

to the right shore, the bottom is sandy and overgrown with *Carex* sp. and *Phragmites communis* TRIN. Close to the left shore, it is sandy, sandy-loamy and covered with *Carex* sp. and *Acorus calamus* L., while the promontory itself is overgrown with *Scirpus lacustris* L. The depth of the bay comes to 7 m.

The B_2 bay (Fig. 6) is situated on the eastern coast of the lake, about 5 km from the sluice at Guzianka. It forms a very deep inlet in the shore but its water is shallow, only 1 m in depth. It is only close to the boundary of the bay that larger depths — to 2.5 m — occur. The shores are marshy, overgrown with willows and alders. Further inland, there is a pine forest. The coastal belt of the bay is overgrown with *Phragmites communis* TRIN., *Scirpus* and *Carex* sp. sp. A wide belt of *Stratiotes aloides* L., exuberantly developed, is parallel to the coastal belt. In its central parts, the bottom of the bay is covered by the meadows of Characeae, *Potamogeton natans* L. and *P. lucens* L. In addition, there are also *Nymphaea alba* L. and *Nuphar luteum* (L.). A fairly thick layer of sediment, white-gray and gray in color, covers the bottom.

4. INDIVIDUALITY OF WATER MASSES IN BAYS

The bays under study are parts of different lakes, have different types of shores and, therefore are, to a different extent, exposed to the action of winds. If the length of a wave runway is different, winds of identical strength may cause, in the vicinities of the bay, a varying turbulence of water. The size of the wave is directly proportional to the length of the runway. When the axis of the bay is perpendicular to the axis of a narrow and long lake, the energy of the wave, in the contact zone, can never be as big as that in the case when the axis of the bay makes up a continuation of the axis of the lake. Therefore in considering the influence exerted by the wind on the waters of the bay, the winds were only taken into account which blew towards the bay, that is, those whose direction do not form, with the axis of the bay, a bigger angle than 90°.

The greatest force would be that of a wind blowing parallel to the bay axis, while a wind, blowing perpendicularly to this axis would have a force whose theoretical value would equal zero, while — in practice — some insignificant action would occur due to the diffraction and interference of the waves.

The following formula was applied by. KAČUGIN (1959) to the analysis of the impact of waves on the shore:

$$E_n = E_1 \cdot \cos \alpha$$

where:

E_n = vector of waving energy, perpendicular to the shore;
E_1 = energy of waving with a definite direction;
α = angle, formed by the line normal to the shore and the direction of the wave run.

The energy of the lacustrine waving, acting on the waters of the bay is proportional to the wind velocity. It depends on the direction in which the waves run when they reach the boundary of the bay.

Since the turbulence, caused by strong winds, may persist for a longer period, the winds, blowing for 5 days, preceding the sampling day (reduced by cos α) have only been considered. The winds, blowing from the bay, have been disregarded.

A mean velocity of the reduced wind has been calculated for each of these 5 days, preceding the sampling day. A general mean velocity of the reduced
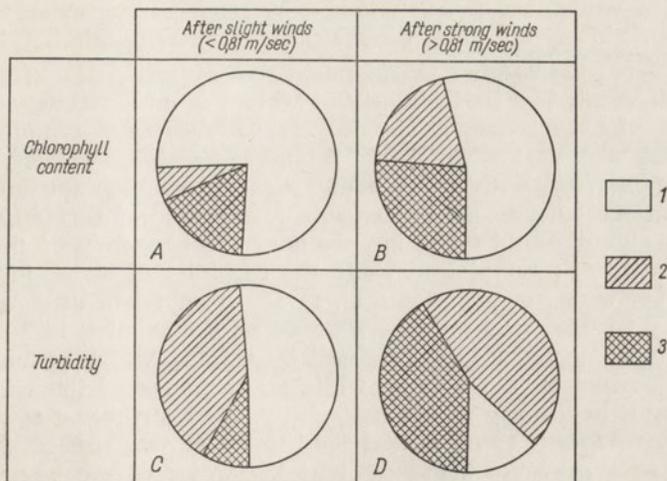
Fig. 7. Frequence of records of smaller, equal and larger chlorophyll contents and turbidity in bay waters as compared with the central basin after the periods of slight and strong winds (per cent of cases)
1 — smaller, 2 — equal, 3 — larger in the bay waters than in the central basin

wind, calculated for all 5-day periods, preceding sampling, amounted to 0.81 m/sec. The values lower than 0.81 m/sec were defined as slight winds and those larger than 0.81 m/sec — as strong winds.

Since the individuality of water masses of the bay is proven by different chlorophyll content and different turbidity of the bay waters as compared with those of the central basin, the number of cases has been calculated in which the turbidity and the chlorophyll content of the bay water were smaller, equal and larger as compared with corresponding figures, concerning the central basin (the entire observation material has been used for this purpose). In the majority of cases, smaller amounts of chlorophyll have been found in bay (60 per cent of cases) than in the central basin (23.3 per cent). Equal amounts have been recorded in 16.7 per cent of cases. On the other hand, the larger, equal or smaller degree of turbidity occurs with much the same size (28.5⁰/o, 28.5⁰/o 43.0⁰/o).

The wind constitutes a factor which disturbs the individuality of the bays. To evaluate its action, the entire observation material has been divided into the following two groups:

1) a material of the series which were sampled during the windless weather or during the period of slight winds (to 0.81 m/sec) and

2) a material, sampled after or during the periods of strong winds.

The number of cases in which the chlorophyll content of the bay water is smaller compared with that of the central basin water considerably increased after the periods of the still (Fig. 7 A). A strong wind decreases the frequency of occurrence of smaller amounts of chlorophyll in the bay and increases that of the cases of equal chlorophyll contents (Fig. 7 B). The number of cases with smaller chlorophyll content of the bay water after a period of strong winds exceeds 1/2 and, after a period of slight winds of 3/4 of all cases of the group under study.

After slight winds, the frequency of occurrence of a greater turbidity in the bay is much lower than that after a period of strong winds (Figs. 7 C, D).

It results from the comparison of particular bays that the effect of wind on bays is different. The individuality of waters is most strongly manifested in the B_2 bay of Lake Bełdany. The July 25, 1960 series of samples has been taken after a period during which the mean reduced wind velocity amounted to 0.15 m/sec (Fig. 8). Within the boundaries of the bay, the quantities of phytoplankton are very small. Likewise, a low degree of turbidity is displayed by the water of this bay. It is only near the boundary of the bay that both the quantity of phytoplankton and the turbidity of water increase. The August 24, 1960 series of samples (Fig. 9) has been taken after a period of a fairly windy weather (the reduced wind velocity amounted to 2 m/sec). The turbidity of the bay water was increased by waving which probably moved sediments, deposited on the bottom, while no exchange of the water masses was caused by it in the bay and, consequently, the distribution of chlorophyll was not changed despite the fact that the bay water was ruffled. It was only on a certain area near the boundary that the water of the bay was mixed with the water of the central basin and this is the reason why the increase in the quantity of phytoplankton was observed not exactly on the boundary of the bay but at a certain distance from it. The conditions that, on November 10, 1960, that is, also after a period of strong winds (0.90 m/sec), were observed in the B_2 bay of Lake Bełdany, are depicted in Fig. 10. The equalization of the chlorophyll content with that, occurring in the central basin, took place on a large area of the bay which, did not, however, comprise even a half of the bay.

The B_1 bay of Lake Bełdany differs from the central basin to a considerably lesser extent than the B_2 bay, although it displays the tendency to retain its individuality and to keep a lower chlorophyll content. When samples were taken after a period of a stronger influence, exerted by the wind on the bay water, an equal chlorophyll content was recorded in the bay and in the central basin. After periods of still weather, the amounts of chlorophyll slightly decreased. On the other hand, the differences in the capability to the diffusion of light indicates the fact that the increase in the turbidity need not necessarily be related with the sediment movement. It may be caused by other factors. Thus, for instance, on July 25, 1960 (Fig. 11), despite the fact that the wind was not very strong (0.57 m/sec) during the preceding period, a larger degree of turbidity was observed in the water of the bay than in that of the central basin (this may well be a result of an intensified development of zooplankton). A similar, although not so distinct, picture has also been recorded in August.

In the Kobyliniec bay M_1 on Lake Mikołajskie, the amount of chlorophyll is, in a larger number of cases, smaller than that in the central basin and, in these cases, it is only on the boundary of the bay that an increase is observed in the chlorophyll content of the water. The conditions that predominated after periods of slight winds (0.30 m/sec) are shown in Fig. 12. The equalization of the chlorophyll content and the degree of the water turbidity between the bay and the central basin takes place after periods of a windy weather.

The T_1 bay of Lake Tałtowisko differs from the central basin in its higher chlorophyll content and it is worth mentioning that the amounts of chlo-
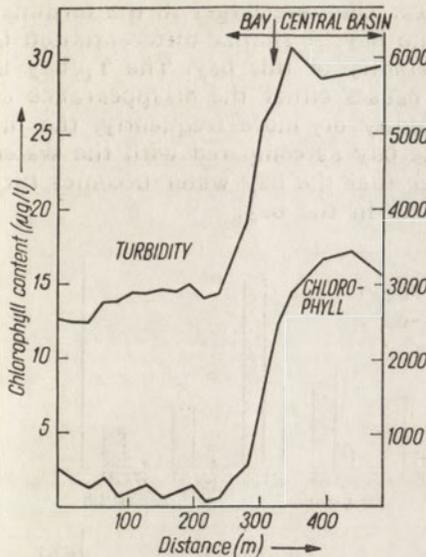
Fig. 8. Comparison of the bay waters and of the adjacent central basin: Lake Bełdany, B₂ bay, August 25, 1960
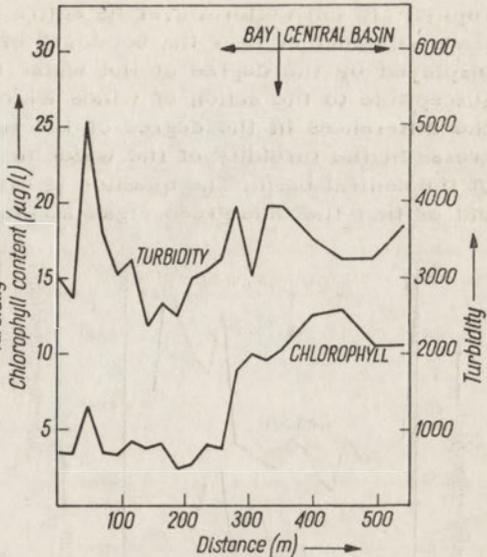
1 — chlorophyll, 2 — turbidity

Fig. 9. Comparison of the bay waters and of the adjacent central basin; Lake Bełdany, B₂ bay, August 24, 1960
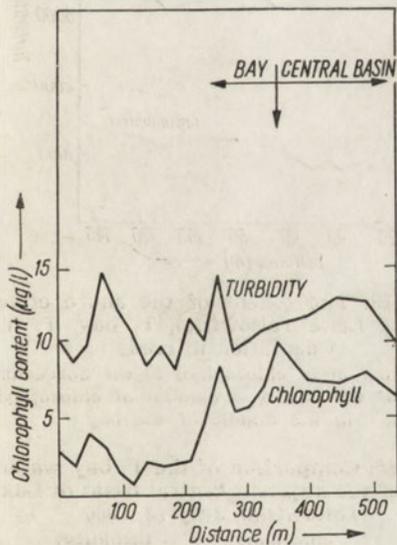
1 — chlorophyll, 2 — turbidity

Fig. 10. Comparison of the bay waters and of the adjacent central basin, Lake Bełdany, B₂ bay, November 10, 1960
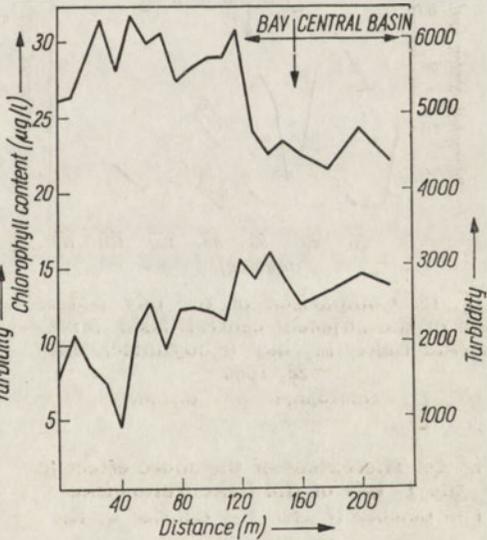
1 — chlorophyll, 2 — turbidity

Fig. 11. Comparison of the bay waters and of the adjacent central basin, Lake Bełdany, B₁ bay, July 25, 1960

1 — chlorophyll, 2 — turbidity

rophyll are not uniform over its entire area. They are larger in the terminal
parts and smaller near the boundary of the bay. A similar differentiation is
displayed by the degree of the water turbidity of this bay. The T_1 bay is
susceptible to the action of winds which causes either the disappearance of
the differences in the degree of the turbidity or, more frequently, the in-
crease in the turbidity of the water in the bay as compared with the water
of the central basin. The question is rather that the bay water becomes tur-
bid or that the blue-green algae accumulate in the bay.
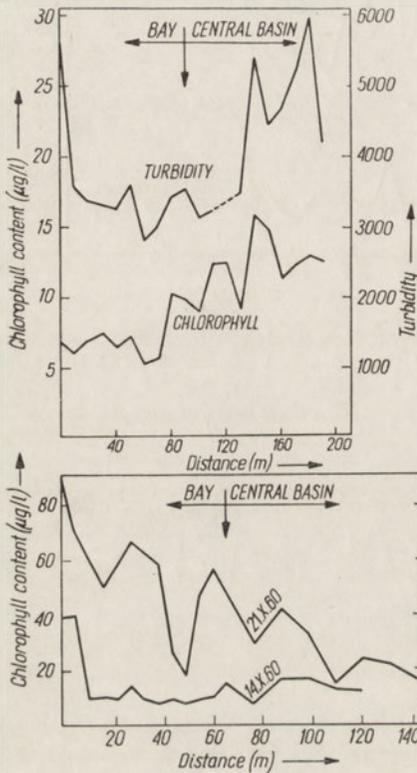
Fig. 12. Comparison of the bay waters
and of the adjacent central basin, Miko-
łajskie Lake, M_1 bay (Kobyliniec), July
23, 1960
1 — chlorophyll, 2 — turbidity

Fig. 13. The extent of the shore effect
in the Lake Tałtowisko, T_1 bay, T_2 in-
dentation in reeds
1 — amount of chlorophyll in the borderline
part of the bay, 2 — amount of chlorophyll
in the middle of the bay

Fig. 14. The extent of the shore effect in
the T_1 bay of the Lake Tałtowisko
1 — October 14, 1960, 2 — October 21, 1960

Fig. 15. Comparison of the T_1 bay waters
and of the adjacent central basin of Lake
Tałtowisko, July 13, 1960
1 — chlorophyll, 2 — turbidity.

In the T_2 indentation on Lake Tałtowisko, the quantities of chlorophyll
display similar properties to those in the bays of Lake Bełdany and in the M_1
bay of Lake Mikołajskie. The quantities of chlorophyll, contained in the wa-
ter within the limits of the indentation, are smaller than those in the waters

of the open lake, the individuality of this area, is, however, of a lesser degree since the reed covered area does not make up a barrier, fully unpermeable for waving and movement of the water masses. The limitation of the exchange of water masses between the indentation and the central basin is possible only during the periods of slight or moderate winds. Stronger winds, particularly those, blowing from the directions causing waving in the vicinity of the area under study, affect the waters of the bay. A high wave passes through the reed covered area and, although it changes its character and becomes a long wave, it stirs the bottom sediments and causes an increase in the degree of turbidity.

Particular series of samples have been taken from the B_1 and B_2 bays of Lake Bełdany on the same day with a time difference of only 1 hour. This material allowed us to compare these bays with each other, as well as to compare particular central basins. Mean quantities of chlorophyll and mean degrees of turbidity of the water of the bays and central basins adjoining particular bays, measured between May 26 and November 10, 1960, are presented in Table 1.

Table I

Turbidity and chlorophyll content of the water in the B_1 and B_2
bays and in the basins of Lake Bełdany

	Chlorophyll content µg/1	Absolute turbidity
Basin 1	11.0	3401
Bay B_1	10.0	4258
Basin 2	10.0	3238
Bay B_2	3.0	2213

The chlorophyll content and the turbidity of the water in different basins of Lake Bełdany are similar to each other which would point out the homogeneity of water masses in these basins, while the chlorophyll content of the B_2 bay is almost three times lower than that of the basin. Much lower is also the degree of turbidity of the water in this bay as compared with the turbidity of the basin. There are no differences in the chlorophyll content of the B_1 bay and of the basin, while considerable differences are recorded in the turbidity of water in the bay and in the basin. The waters of both these bays differ from the waters of the basin.

5. SHORE EFFECT

Phenomena, resulting from the action of the drift currents have for a long time been well-known to the planktonologists. They consist in the accumulation of some planktonic forms close to the shores which are exposed to the action of winds. This particularly concerns some blue-green algae such as, for instance, *Gloeotrichia* and *Anabaena*. These organisms, lighter than water, accumulate close to its surface and are transported by the landward drift current. Near the shore, they enter the action zone of the longshore current, moving along the shore, and accumulate in the bays. Such an accu-

mulation of plankton and, particularly, algae in the end parts of bays has been called by WELCH (1952) a „shore effect". By this term, the author also means an increased degree of turbidity in coastal samples. The shore effect occurs mostly in the bays of Lake Tałtowisko where, in the T_1 bay, it is recorded in almost all series. This phenomenon is very distinct in September and October. It also occurs in the T_2 indentation of Lake Tałtowisko but its intensity is smaller. A mean chlorophyll content per liter of water in the T_1 and T_2 and the amount of chlorophyll in the parts, covered by the shore effect, are shown in Fig. 13. The amount of chlorophyll close to the shore is a few times larger than in the border areas of the bay. The range of the shore effect usually reaches a few meters from the end of the bay. Fig. 14 depicts the chlorophyll content of the T_1 bay of Lake Tałtowisko on October 14 and 21, 1960. On October 14, 1960, the shore effect in the T_1 bay was observed only in the samples, taken in the area, directly bordering on the end of the bay. On October 21, 1960, during the period of the most intensive development of blue-green algae, an almost entire surface of the T_1 bay was covered with a thin layer of blue-green algae. It was also in this case that the amount of algae was larger near the end of the bay.

The shore effect may persist even a few days after the cessation of its causes. The July series of samples from the T_1 bay of Lake Tałtowisko was taken after a few days of very slight winds. Stronger winds were recorded during a period which preceded by 102 hrs the observation time and then, their velocity came to 5 m/sec. On the other hand, a mean velocity of the reduced wind for the last 90 hrs amounted to only 0.15 m/sec but, despite this fact, the shore effect was very distinct (Fig. 15). It seems that this phenomenon may persist at least for 100 hrs.

The October, 1960 sampling materials from the T_1 bay and the T_2 indentation of Lake Tałtowisko (Fig. 13) may supply certain data on the origin and disappearance of the shore effect. During a four-day period which preceded the sampling, the wind was fairly strong and, in this connection, on October 14, 1960, a great accumulation of algae was observed in the terminal part of the T_2 indentation. At the same time, similar conditions were recorded in the T_1 bay in whose terminal part algae were also accumulated. A week later, the conditions changed and the wind began to blow towards the T_1 bay. On October 21, 1960, the drift and combined currents, evoked by this wind, caused a considerable decrease in the shore effect within the range of the T_2 indentation. A part of algae might be carried out by these current from the indentation. A drop in the chlorophyll content of the water in the terminal part of the indentation could be hardly explained by the death of algae since a continuous increase in the chlorophyll content of the water was, at the same time, observed in the T_1 bay. The same wind may, in some bays, cause the increase and, in some others, a decrease in the intensity of the shore effect. This depends on the situation of the bays.

6. BAY BOUNDARY

The influence exerted by the wind on the bay, takes in not only the exchange of water masses and the occurrence of the shore effect, but also, much more frequently, certain displacements of water masses which do not yet make up an exchange of water masses but consist only in shifting of the

boundary between these masses. The boundary of the bay, not in all cases coincides with the boundary between water masses of the bay and those of the central basin which was stated during the investigation. In most cases, the boundary zone between water masses does not run along the morphometric boundary but is shifted toward the inner part of the bay. This entering the territory of the bay by the water masses of the open lake is particularly intensive during the periods of stormy weather and, in the bays with only a slight individuality, it leads to a complete mixing of water masses. Opposite conditions may also be recorded under which the area of the boundary water masses is situated outside the morphometric boundary of the bay, forming a bulge, turned towards the central basin. In the majority of cases, the wind does not cause the exchange of water masses. It is only shifting the boundaries of these masses that is evoked by the wind which may also produce the shore effect.

7. SUMMARY

On the basis of the analysis of the phytoplankton and seston quantities it has been stated that small lacustrine bays may keep the individuality of their water masses.

The small lacustrine bays usually contain smaller amounts of phytoplankton than those, recorded in the waters of adjacent basins.

It is more than once that the morphometric boundary of the bay does not coincide with the boundary of the water masses of the bay and of the central basin.

A phenomenon of shifting the boundary between the waters of the bay and those of the central basin towards the inner part of the bay is frequently caused by the wind; sometimes, the boundary of the bay may, however, be shifted towards the central basin.

In the bays with a greater extent of isolation even strong winds, causing considerable waving, do not cause mixing water masses of the bay and of the central basin.

The turbidity of the water, evoked by tearing away the sediments, deposited on the bottom, may be caused by strong waving within the range of the bay.

The drift current producing winds may be a frequent cause of the „shore effect", that is, the accumulation of great quantities of phytoplankton on the surface of the water.

8. STRESZCZENIE

Na podstawie analizy ilości fitoplanktonu i sestonu stwierdzono, że małe zatoczki jeziorne mogą zachowywać odrębność swych mas wodnych. Zatoczki jeziorne przeważnie posiadają mniejsze ilości fitoplanktonu niż wody przyległych plos. Morfometryczna granica zatoki nieraz nie pokrywa się z granicą mas wodnych zatoki i plosa.

Silne wiatry często wywołują zjawisko przesuwania się granicy między wodami zatoki i plosa w głąb zatoki; jednak obserwuje się, że granica zatoki ulega przesunięciu w stronę plosa. Nawet silne wiatry wywołujące duże falowanie nie powodują w zatokach o większym stopniu izolacji wymieszania mas wodnych zatoki i plosa. Silne falowanie powodować może w obrębie zatoki zmącenie jej wód przez poderwanie osadów leżących na jej dnie.

Wiatry powodujące powstawanie prądów dryfowych są często przyczyną występowania w zatokach „zjawisk brzegowych", czyli nagromadzenia na powierzchni wody dużej ilości fitoplanktonu.

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ZOOPLANKTON AND TEMPERATURE-OXYGEN CONDITIONS OF TWO ALPINE LAKES OF THE TATRA MOUNTAINS

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ABSTRACT

The lakes studied were the Czarny Staw (elevation 1620 meters) and the Zielony Staw (elevation 1671 meters) in the valley Dolina Stawów Gąsienicowych. Collections were made from April 6, 1962 till April 16, 1963. The density changes and distribution of zooplankters are discussed in connection with the thermal and oxygen conditions. Highest densities of the dominants (Cyclops tatricus Kozm., *Keratella quadrata testudo* (Ehrbg.) and *Polyarthra dolichoptera* Idelson) were observed during the summer stagnation, lasting 1.5—2.5 months. The vertical distribution shows maximum densities in the doseto-surface zone and in the bottom water layer, where in winter oxygen depletion was noted. The accumulation of zooplankters at the bottom suggests that they are capable of exploiting the bottom food resources. Horizontal distribution is patchy to a high degree. Great quantitative and qualitative changes of zooplankton of both lakes (decline of *Cladocera*, mass development of Rotatoria) has taken place since 1949 which may be the effects of stocking the lakes with fish.

CONTENTS

1. INTRODUCTION

Of the numerous papers on the Tatra lakes many deal with zooplankton, mainly of faunistic value and based mostly on single qualitative samples without any depth records. They give no information whatever concerning density and distribution of plankton (Wierzejski 1883, Minkiewicz 1912, 1917, Lityński 1913, Gajl 1934). Some of them describe lakes located within the forest limit, i.e. below the alpine zone proper and are only partially based on quantitative samples (Gajl 1926) or cover

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just the short period of summer stagnation (KUBIČEK 1958, KUBIČEK and VLČKOVA 1954, ERTL and VRANOVSKY 1964).

The zooplankton density in oligotrophic cold lakes of the alpine region seems to be an interesting topic because of the extremely short summer stagnation period, and of the thick and long lasting ice-and-snow cover. Both these greatly influence the primary productivity (RODHE 1962), and thereby the density and distribution of zooplankton.

This paper is intended to give quantitative data on zooplankton of two alpine lakes of the Tatra Mts. (density, distribution and vertical migration of plankters) in connection with the temperature and oxygen changes.

2. TERRITORY, METHODS

The two lakes studied, the Czarny Staw and the Zielony Staw, are situated in the Tatra Mts. in the valley Dolina Stawów Gąsienicowych *. Both of them, similarly as the majority of Tatra lakes of higher altitudes, are oligotrophic ** and both lack oxygen in their deepest parts (oxygen depletion) which is restored annually during the winter stagnation period (micromeroeutrophy — OLSZEWSKI 1948, 1953). Both lying among granite boulders and gravel, sheltered on the east, south and west by high cliffs, they have no littoral zone at all.

As to their hydrography (SLIWERSKI 1938) and physical and chemical conditions (SZAFLARSKI 1936, OLSZEWSKI 1939), they are typical representatives of Tatra lakes from above timberline (Table 1).

Samples were taken at intervals of 6—8 weeks from April 6, 1962 to April 16, 1963. The sampling stations were three in each lake, surrounding the deepest spot, about 20 m from each other, forming a triangle. In April, May and July 1962 additional samples were taken from each lake from a triangle of sampling stations establi-

Table I

Hydrographical data of the examined lakes (compiled from SLIWERSKI 1938* and SZAFLARSKI 1936)

Lake	Elevation m	Surface ha	Capacity m³	Maximum depth m	Average depth m	Secchi discread-ing, summer stagnation m	Time of thawing	Time of freezing
Czarny Staw	1620	179.44	3.797.800	51.0	21.1	12	15-30.V	1-15.XI
Zielony Staw	1671	34.44	260.500	15.0	6.8	10	1-15.VI	15-30.X

* This paper contains bathymetry, too.

shed at a depth of 4—6 meters. Samples were taken with a five-liter Patalas plankton sampler (PATALAS 1954). In the Zielony Staw they were taken at 1 meter intervals from top to bottom, while in Czarny Staw at 1 meter intervals from depths 0—10 m and 40—50 m and at 5 meter intervals from depths 10—40 m (giving 25 samples). Qualitative samples were taken simultaneously.

For the study of diel vertical periodicity, samples were taken at the same depths

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* These names mean "the Black Pond", "the Green Pond" an "the Valley of Gąsienica's Podds" respectively.
** The Czarny Staw is ultraoligotrophic according to OLSZEWSKI (1948, 1953).

from one station at six-hourly intervals (6.00, 12.00, 18.00 and 24.00). This sampling programme was carried out on August 30—31st, 1962 and on February 19—20th, 1963 at Zielony Staw and on August 28—29, 1962, and on February 21—22 1963 at Czarny Staw. A calculated variation index was used to interpret the vertical distribution of three important species. For each depth, a mean number was calculated using not only the four — six-hourly samples at the above station but also the normal samples obtained from the two other stations taken only once during the 24 hours. The difference between the mean number and the individual sample number for each depth was calculated and, for each six-hourly series of samples, these differences were summed. This total represents the variation index.

Plankton samples were strained through bolting silk of 40μ mesh-size and preserved in 4⁰/o formalin. Entire samples were counted.

Dissolved oxygen concentration was determined with the standard WINKLER method. Water for this purpose was run from the sampler through a rubber pipe, attached to a brass tap provided inside the sampler with a wide bolting-silk-covered funnel.

Temperatures were taken with a decimal thermometer, fixed inside the sampler.

3. RESULTS

TEMPERATURE

Temperature curves (Figs 1 and 3) are averages of the three vertical series. Noteworthy is the shifting of the winter thermocline in the Czarny Staw, its stepped shape, observed at all the three sampling stations (Fig. 1, April 6, 1962) and also the gentle slope of winter thermocline in the Zielony Staw (Fig. 2, April 11, 1962 and May 23, 1962).
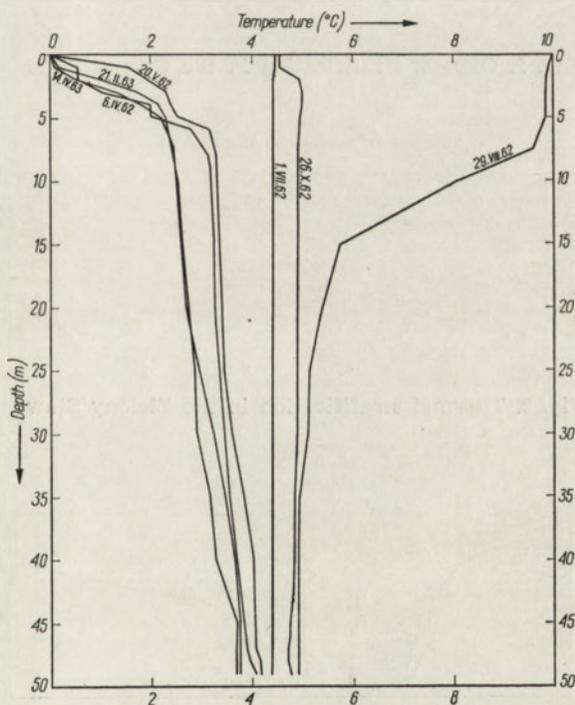

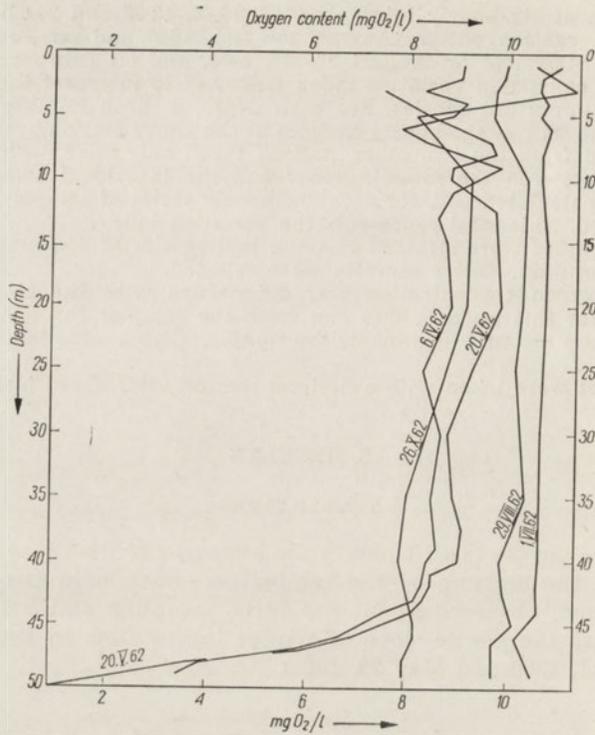Fig. 1. Thermal stratification in the Czarny Staw
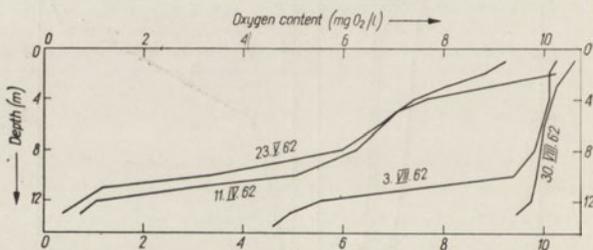
Fig. 2. Oxygen stratification in the Czarny Staw

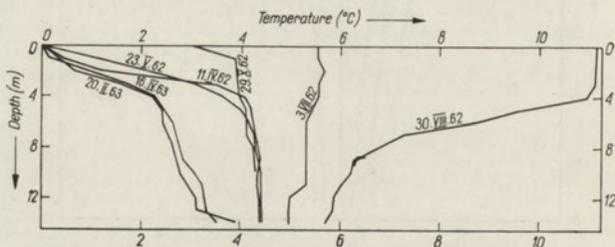

Fig. 3. Thermal stratification in the Zielony Staw

Fig. 4. Oxygen stratification in the Zielony Staw

DISSOLVED OXYGEN

The results of dissolved oxygen determinations are plotted in Figs 2 and 4. It is evident from the curves for Czarny Staw (Fig. 2) that this water body displays a very complex oxygen stratification during the winter stagnation period (April 6, 1962 and May 20, 1962).

Three layers can be discerned. The top layer (0—12 m) with variable oxygen conditions, the median one (12—40 m) which displays the most uniform dissolved oxygen concentrations and the third and last layer (40—50 m) with a rapid decline of oxygen content.

The oxygen stratification of Zielony Staw (Fig. 4) during the winter stagnation period is less complicated. The curves for April 11, 1962 and May 23, 1962 are similar to the lower parts of the curves for Czarny Staw, but the concentration of oxygen in the near-bottom samples was here still lower.

SPECIES COMPOSITION OF ZOOPLANKTON

In the course of the year's study, three species were found to be permanently dominating. These were the copepod *Cyclops tatricus* Koźm. and the rotifers *Polyarthra dolichoptera* Idelson and *Keratella quadrata testudo* (Ehrb.). Out of the remaining species only one, namely *Holopedium gibberum* Zaddach, was taken with a five-liter sampler while all the other could be found only in highly concentrated qualitative samples. These were in the Czarny Staw: *Bosmina longirostris* O. F. Müller f. *similis* Lill. (f. *tatrensis* Mink.), *Keratella cochlearis cochlearis* (Gosse), *Kellicottia longispina* (Kell.), *Notholca squamula* (Müller), and in the Zielony Staw: *Eucyclops serrulatus* (Fisch.), *Bosmina longirostris* O. F. Müller f. *similis* Lill. (= f. *tatrensis* Mink.)*, *Alona quandrangularis* (O. F. Müller), *Acroperus harpae* f. *frigida* Ekm., *Scapholeberis mucronata* O. F. Müller *cornuta* Schoedler, *Holopedium gibberum* Zaddach, *Keratella cochlearis cochlearis* (Gosse) and *Notholca squamula* (Müller).

Bosmina longirostris was up to now reported as the sole Tatran bosminid from two lakes only (the Morskie Oko and the Czarny Staw at the food of Rysy). *Scapholeberis mucronata* was known from one lake — the Staw Smreczyński (Lityński 1913, Minkiewicz 1917).

There were found no net phytoplankters.

DENSITY OF THE DOMINANTS

Cyclops tatricus Koźm.

This was a dominant species in both lakes but its density in the Zielony Staw was several times higher (Fig. 5). Highest density of mature individuals was observed in February. The males appear at the end of the short summer stagnation period, but their maximum is observed as late as January (Czarny Staw) or February (Zielony Staw), at the time when the females begin to carry eggs. The average number of eggs per egg-carrying female was 9.13 in the Czarny Staw (minimum 3, maximum 14 eggs) and 17.35 eggs in the Zie-
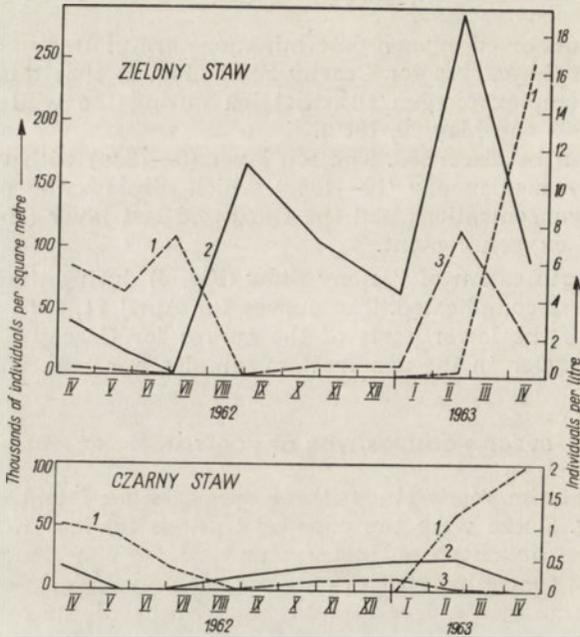
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* Minkiewicz 1916.

Fig. 5. Abundance of *Cyclops tatricus* Koźmiński in the Czarny Staw
and the Zielony Staw

1 — nauplii, 2 — adults (including males), 3 — males

lony Staw (minimum 10, maximum 27 eggs). On the other hand, the percentage of females carrying eggs was higher in the Czarny Staw (24% Febr. 21, 1963 and 27% April 14, 1963) than in the Zielony Staw (7% Febr. 20, 1963 and 25% April 16, 1963).

During the whole year there was found not a single individual at the copepodit stage and the species simply appeared as new mature specimens causing a remarkable increase of density of adult copepods which in the Zielony Staw was very rapid and occurred in February and in the Czarny Staw was more gradual and lasted from August till February.

Polyarthra dolichoptera IDELSON

This species occurred all year round in both lakes (Fig. 6), and was markedly denser in the Czarny Staw, except for the peak developmental period. Because of the low frequency of sampling the real time of maximum growth was difficult to detect. However it is clear that the maximum in the Czarny Staw occurred earlier than in the Zielony Staw.

Keratella quadrata testudo (EHRBG.)

Throughout the year this species was more abundant in the Zielony Staw (Fig. 6). The changes in density are in this species more gradual than in *P. dolichoptera*, the peak densities in both lakes being rather mildly pronounced. Also they coincide they with the short summer stagnation period and not at the same time in both lakes. The July/August pulse of this species in the Zie-

lony Staw was earlier than the October pulse in the Czarny Staw. This is very interesting as Czarny Staw thawed earlier and begans its summer stagnation period earlier than Zielony Staw.

Holopedium gibberum ZADDACH

This species was taken in small numbers in the Zielony Staw only during the summer stagnation period (August 30 and October 29, 1962). A winter pulse of this species in the Zielony Staw was found in 1949—1950 by OLSZEWSKI (unpublished, see Table 2).

VERTICAL STRATIFICATION

The diel changes of vertical strafification of the zooplankton in both lakes were studied during the months of August and February. The variations indices of density differences (as described in Methods) for one station at different times of day revealed that the dominant species exhibited no diel vertical periodicity. For every six-hourly series of samples, the depth above which there were the same number of individuals as below was determined and this depth was similar, within one metre, for all six-hourly time series.

On the other hand, the seasonal periodicity of the dominant species is well marked.
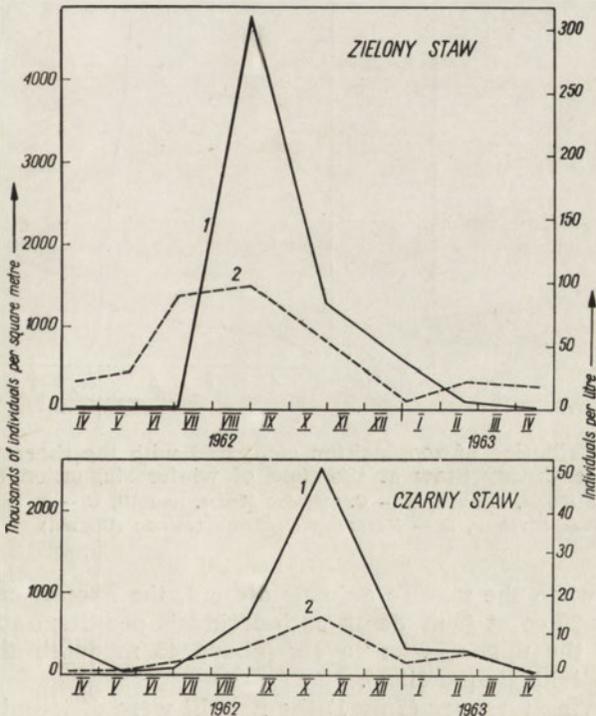

Fig. 6. Abundance of rotifer dominants in the Czarny Staw and the Zielony Staw
1 — *Polyarthra dolichoptera* IDELSON, 2 — *Keratella quadrata testudo* (EHRBG.)

Cyclops tatricus Koźm.

In the Czarny Staw at the end of the winter stagnation period both the nauplii and the mature individuals congregated at two distinct depths, near the surface and at the bottom (Fig. 7). The upper congregation coincides with the thermocline, where the oxygen conditions are highly diverse and fluctuating, and the lower in the near-bottom layer poor in oxygen, with a steep oxygen gradient.
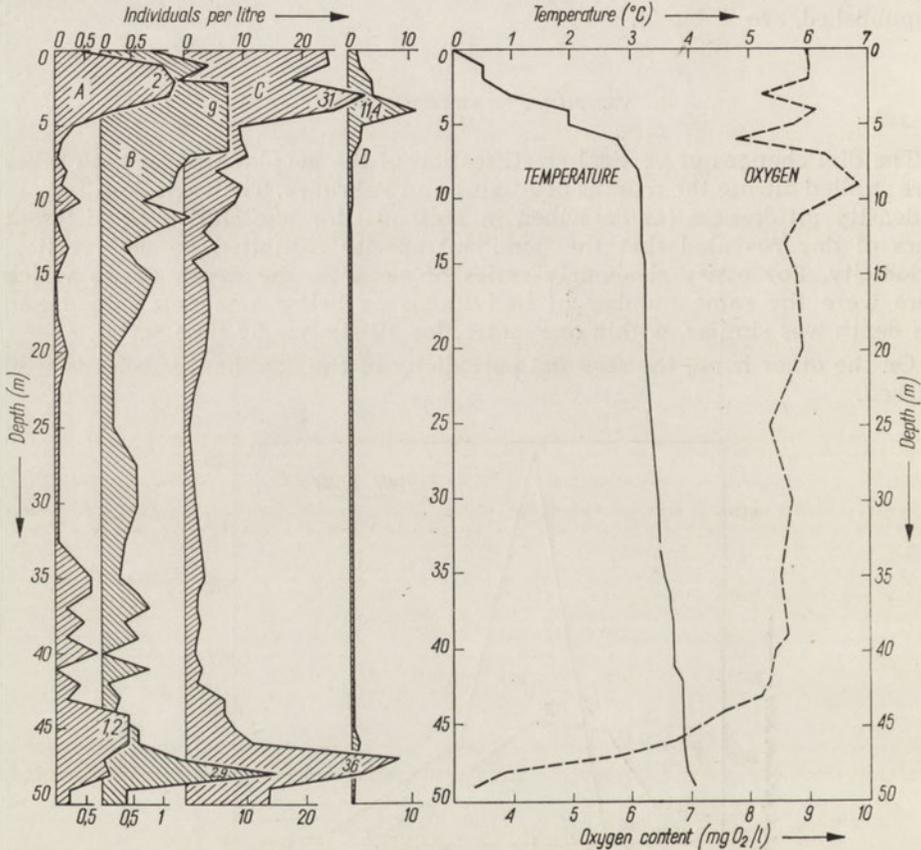

Fig. 7. Vertical distribution of zooplankton compared with the thermal and oxygen stratification in the Czarny Staw at the time of winter stagnation (April 6, 1962) A — *Cyclops tatricus* Koźm. mature, B — *C. tatricus* Koźm. nauplii, C — *Polyarthra dolichoptera* Idelson, D — *Keratella quadrata testudo* (Ehrbg.)

At the thaw when the mature animals die out, the nauplii crowd close to the bottom (May 20 — at 49 m depth 33 individuals per liter) abandoning almost completely the upper water layers (above 45 m depth the density is lover then 0.5 individuals per liter).

During the spring turnover (July 1) the nauplii were distributed evenly up to 15 m (density 0.2—0.5 individuals per liter) and were lacking absolutely above this depth.

During the summer stagnation (Fig. 8) the population of *C. tatricus* con-
sisted of mature animals exclusively, its greatest density coinciding exactly
with the thermocline (10 m depth). This top density was found to remain at
the same depth in the four-times-a-day sampling.

At the time of the autumn turnover the mature copepods were scattered
evenly throughout the volume of water (0.2—0.7 individuals per liter) with
a slight increase in density close to the bottom (1 individual per liter at 49 m
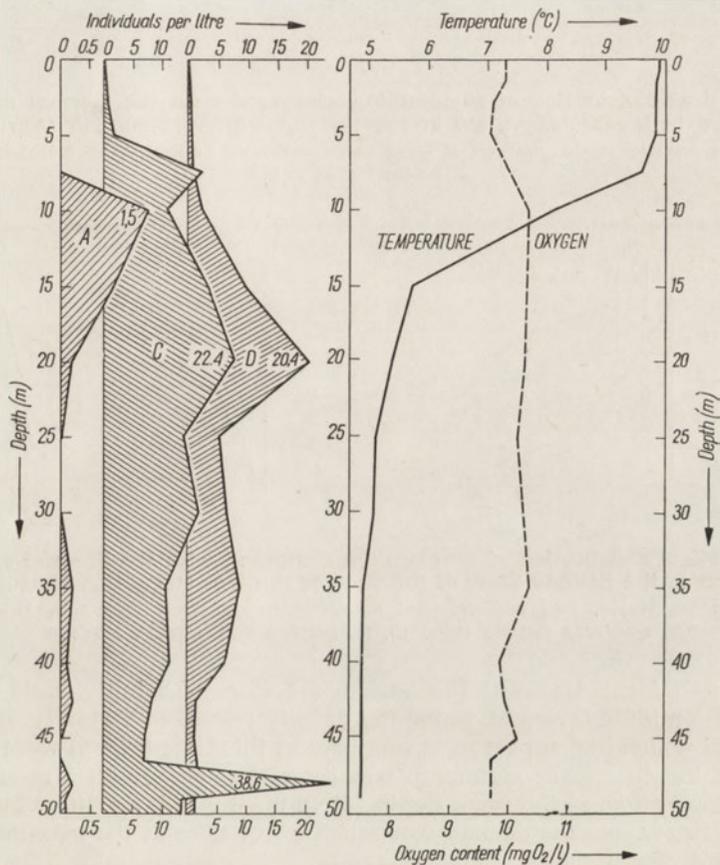depth). In 5—6 weeks after the final freezing (January 3) a pronounced maxi-

Fig. 8. Vertical distribution of zooplankton compared with the thermal and oxygen
stratification in the Czarny Staw at the time of summer stagnation (August 29, 1962)
A — *Cyclops tatricus* Kožm. mature, C — *Polyarthra dolichoptera* Idelson, D — *Keratella
quadrata testudo* (Ehrbg.)

mum was observed just below the ice cover (at 2 m—2.6 individuals per liter)
at the level of thermocline and of large oxygen fluctuations. From 5 meters
down to the bottom the density of *C. tatricus* was even, amounting to 0.1—0.2
individuals per liter.

After another seven weeks (February 21) this close-to-surface maximum of
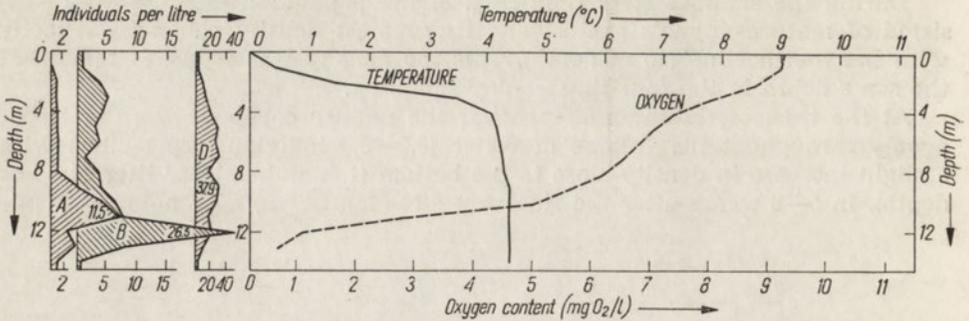mature *Cyclops* was found again (at 2 m—3.6 individuals per liter) but a se-

Fig. 9. Vertical distribution of zooplankton compared with the thermal and oxygen stratification in the Zielony Staw at the time of winter stagnation (April 11, 1962) A — *Cyclops tatricus* Koźm. mature, B — *C. tatricus* Koźm., nauplii, D — *Keratella quadrata testudo* (Ehrbg.).
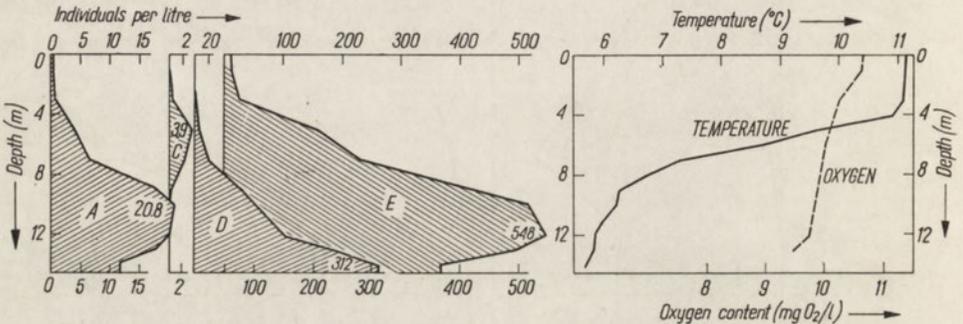

Fig. 10. Vertical distribution of zooplankton compared with the thermal and oxygen stratification in the Zielony Staw at the time of summer stagnation (August 30, 1962) A — *Cyclops tatricus* Koźm., mature, C — *Holopedium gibberum* Zaddach, D — *Keratella quadrata testudo* (Ehrbg.), *Polyarthra dolichoptera* Idelson

cond one had formed also at the bottom (at 48 m—0.8 individuals per liter) while in the middle layers of water the density remained virtually unchanged. The nauplii which had appeared in numbers at this time (Fig. 6) were similarly distributed but the upper maximum was somewhat deeper (at 5 m—2 ind. per liter) the lower was at the same depth (at 48 m—1.9 ind. per liter) in the inter mediate water layers the density was much lower than at the maximum points (0.3—1.5 ind. per liter).

Towards the end of the winter stagnation (April 14) the upper maximum of mature individuals diminished visibly while the lower maximum increased. The lower maximum of nauplii also increased (up to 3.8 individuals per liter), and has moved deeper, down to 49—50 m. The nauplii of the upper maximum scattered over depths from 2 to 30 m.

In the Zielony Staw the vertical stratification of adult copepods as well as that of juvenile stages was much more stable. Even during full turnover stratifications similar to those of April (Fig. 9) and August (Fig. 10) were encountered. So the peak densities were detected during the whole year in the strata close to the bottom, which suffered oxygen depletion during the long lasting winter stagnation. The maximum, which in April (Fig. 9) was

found at 11—12 m, had shifted down to 13 m at the end of the winter stagnation. At the beginning of the spring turnover (July 3), when mature individuals were already almost absent, a maximum of the nauplii was encountered at 14 m. A similar shifting of the maximum density to the very bottom was observed in the first months of winter stagnation when the whole population consisted of adult copepods alone. The August maximum of 9—12 m (Fig. 10) shifted to 11—13 m at the end of fall turnover (October 29) and after 6—7 weeks of winter stagnation (January 2) it moved still lower, to 14 m. It stayed at this depth until February 20 and moved upwards up to 12m not until April 16 (adults and nauplii).

Polyarthra dolichoptera IDELSON

In the Czarny Staw this species was distributed evenly throughout the volume of water, with a small increase in density just above the bottom. Such state persisted from before the spring turnover (May 20), during it (July 1), during the summer stagnation (August 29 — Fig. 8) and till the fall overturn (October 26). At the height of winter stagnation the changes in distribution were similar to those of *C. tatricus*. First of all a pronounced increase in density was observed just below the ice cover (January 3—211 individuals per liter at 1 meter). Later (February 21) it extended down to 25 m and at the end of stagnation another maximum occurred at the bottom (April 14, 1963 and April 6, 1962, too. Fig. 7).

In the Zielony Staw *Polyarthra dolichoptera* IDELSON was dispersed evenly throughout the volume of water throughout the winter stagnation (Fig. 9) and had a marked peak at the bottom during the summer stagnation and during both the spring and the fall turnovers (Fig. 10).

Keratella quadrata testudo (EHRBG.)

Its dispersion in the Czarny Staw remained fairly even from the thaw (May 20) until the fall overturn was in full swing (October 26). Somewhat exceptional was the situation on August 29 (Fig. 8) when a visible maximum was found at 20 m. At the time of winter stagnation the density was high at 1—5 m, while below 10 m it was very low.

In the Zielony Staw the vertical stratification of *K. quadrata testudo* was very similar to that of *P. dolichoptera* throughot the year. The only differences were that the close-to-bottom maximum appeared no sooner than August 30 (Fig. 10) and persisted till January 2 (a slight maximum at 12 m was found even on February 20) and that it was at 12 m instead of 14.

Holopedium gibberum ZADDACH

This species was taken only in the Zielony Staw at the summer stagnation period (Fig. 10). In contrast to the three species discussed above it occurred only in the upper layers. Not a single specimen was found below 10 m.

HORIZONTAL DISTRIBUTION OF ZOOPLANKTON

The horizontal distribution of dominants proved to be highly differentiated, especially at the end of winter stagnation, this differentiation being at this time fairly stable (all-day-sampling). The differential horizontal concentrations were most remarkable in the Zielony Staw in the case of *C. tatri-*

cus. Differences in density of adult copepods from stations situated at a distance of 20 m reached 446 percent.

At the stations, located near the shore (average for 3 stations at 4—5 m depth) the density was much lower than at the deepest spot (average for 3 stations, too). This difference was most striking in the case of nauplii — the layer 0—4 m at the deepest spot contained 22 times as many nauplii as did the same layer on the shallow.

4. DISCUSSION

THERMAL AND OXYGEN CONDITIONS

The data on the thermal règime of Tatra water bodies are rather fragmentary (BIRKENMAJER 1901, LITYŃSKI 1914, SMOLEŃSKI 1932, SZAFLARSKI 1932 and 1936, STANGENBERG 1936). A full account of the thermal and oxygen conditions during winter stagnation can be found first in the papers by OLSZEWSKI (1948, 1953) which cover also the Czarny Staw and the Zielony Staw.

The rapid decline of oxygen contents in the deeper regions of Czarny Staw (Fig. 2) is typical of all the deep Tatra lakes. OLSZEWSKI (1948) presumed it to result from exothermic processes occuring in the pelogene and producing above the bottom a layer of water rich in dissolved solids. At the time of winter stagnation the water of this layer is more heavy because of the admixture of soluble solids, and, besides it is warmer than that of the overlaying strata (3.7°C — Fig. 1), so it is still more heavy. Being heavier it flows down the steep slopes of the basin and gathers in the deepest part of the lake (micromeroeutrophy).

The way these layers arise in the Zielony Staw must be somewhat different. In spite of the smaller area of bottom a much more severe oxygen depletion was observed there (Fig. 4). OLSZEWSKI (1948) suggested that Zielony Staw recceives a non-freezing underground inflow from the lake situated higher above — the Kurtkowy Staw. According to this idea the eutrophized bottom-water from the latter flows into the Zielony Staw and, being warmer and heavier accumulates on the bottom there. This sounds possible as it was observed in 1961/62 that the water level of the Kurtkowy Staw drops 5 m during the winter.

During the short summer stagnation there is no oxygen depletion in the bottom water layers, contrary to the winter conditions. In wintertime the bottom water temperature is 3.7°C—3.8°C, so a slight rise of temperature makes the water more heavy and still more inclined to gather in the deepest places in the above mentioned way (Fig. 1, Febr. 21, 1963; April 11, 1963; April 6, 1962). In summer a similar rise of temperature acts in the opposite way. A rise above 4.9°C makes the water lighter, thus reducing to some extent the influence of dissolved matter (Fig. 1, August 29, 1962). The mixing of water which is strong at summertime has some influence here, too. Of some importance is also the amount of decomposing organic matter low at this time as greatest zooplankton densities (and highest primary productivity probably too) occur from August till October.

The oxygen depletion processes in both the studied lakes are accompanied by a slight rise in temperature. This was observed in the Zielony Staw (Febr. 20 — April 16, 1962; Fig. 3) as well as in the Czarny Staw bellow 20 m depth (April 6 — May 20, 1962 and February 21 — April 14; Fig. 1).

The shifting of the thermocline in the Czarny Staw by one meter down (February 21 — April 14; Fig. 1) was probably due to the thawing of lower most layers of ice as new layers of secondary ice gathered on top. A rise of water level caused by this "exchange" of subsequent layers of the snow-and-ice cover was already observed in the Tatras by OLSZEWSKI (1948).

The "stepped" shape of the thermocline of April 6, 1962 resulted probably out of several periods of more intense circulation during the fall turnover.

The pronounced rise of metalimnetic temperature at the end of winter stagnation (April 6 — May 20, 1962; Fig. 1) was probably due to partial thawing (on May 20 about 40 percent of total area was ice-free) and to the now running southern inflows which since April transported the sun-warmed water under the ice-cover (on May 19, 1962 — 6°C)*.

On the other hand the smoother shape of thermocline observed twice in the Zielony Staw (April 11 — May 23, 1962 and February 20 — April 16, 1963; Fig. 2) was presumably induced by the underground inflow and outflow of water, both of them running throughout the winter stagnation period.

Thus the long-lasting winter stagnation is by no means a period of inactivity in either of the studied lakes. Thermal as well as oxygen stratification undergoes during this period big changes due to internal, chemical and external, physical factors. In the considered lakes both the spring and the fall turnovers are long and thorough (holomixis) whereas the summer stagnation is extremely short, lasting from one and half to two and half months. The summer stagnation is shorter in the Zielony Staw which lies 50 m higher and is more shaded.

ZOOPLANKTON

In spite of large differences in density and in vertical distribution of the dominants the course of density changes of each of them is similar in both lakes. The rotifer pulse which occurs earlier in the Zielony Staw in spite of the much later thaw results probably from the non-freezing underground inflow. This inflow enriches the waters of the Zielony Staw in biogenic salts which cause rapid growth of nannoplankton thus providing food for zooplankters. The same inflow carries in organic matter which may be important food for sedimentators.

Our data imply that *C. tatricus* Kozm. is a decidedly monocyclic species in Tatras Lakes in contrast to the studies of RUTTNER (1929) on Lunzer Untersee which showed this species to be entirely acyclic.

RUTTNER (1929) published data concerning *Cyclops strenuus* FISH., but the copepods from Lunzer Untersee and from several other Alpine lakes were given thorough morphometric study by RZÓSKA (1927, 1930) and KOZMIŃSKI (1927, 1932 and 1936) and were found to belong to a distinct species, new to science, the *Cyclops tatricus* Kozm. According to KOZMIŃSKI (1933) this is the most widespread copepod of alpine and arctic lakes. Most probably the majority of reports of *C. strenuus* (esp. of the so called littoral form) from these lakes are in fact based on misdeterminations of *C. tatricus* Kozm.

In the Czarny Staw and the Zielony Staw there is only one generation of *C. tatricus* yearly. This is easy to detect although the maturing periods of

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* In the still preserved air holes it was possible to see that water level raised about one meter.

individual copepods are highly dispersed in time and therefore the density maxima are not sharply delimited. In the Zielony Staw females occur even uninterruptedly. The growth periods of particular individuals may vary in time as much as 5 month — the nauplii are noted from March on till August. Presumably in Lunzer Untersee this species is not acyclic, but because of still bigger dispersion in time of individual growth periods any given growth stage can be found at any season.

Taking this into account it is striking that no copepodites were found in the pelagial of either the Czarny Staw or the Zielony Staw. If the difference in time between the growth periods of individual copepods ranges 5 month the copepodites should be found from June till November. During this period samples were taken three times and not a single individual at either the metanauplius IV or the copepodite stage was found. This implies that *C. tatricus* spends its copepodite period in the bottom deposits and the lowermost water layers. It is possible, that a part of this period it spends as a resting stage, but nevertheless the development from the last nauplius stage to the maturity must be undergone in close conection with the bottom habitat. In other words the main species of pelagic zooplankton of both reservoirs, constituting more than 80% of its biomass, spends a large part of its life in this habitat living on the bottom food resources. This way the biomass of the most important pelagic consumer is growing at the cost of the bottom zone.

Perhaps the bottom zone is an important trophic source not only for the copepodite stage. The vertical distribution of nauplii as well as of mature copepods shows all year round a markedly higher density close to the bottom. In the Zielony Staw almost all the population was found always near the bottom, in the deep places where highest degree of oxygen depletion was discovered, due to processes of decomposition. The copepods avoided the shallow, well aërated regions and so did the nauplii. In the Czarny Staw there were most often simultaneously two peaks of mature copepods density, the bottom and the metalimnetic one. The nauplii formed usually only one peak, at the bottom. Similar patterns of vertical distribution were observed in rotifers.

The vertical disposition of zooplankters is very stable as it was shown by the sampling at six hours intervals. Maximum densities are encountered in the zones of rapid temperature changes (the winter and summer upper maximum in the Czarny Staw) and in the zones of rapid oxygen contents changes (the upper winter maximum in the Czarny Staw and the bottom winter maximum in the Czarny Staw and Zielony Staw). Thus in the Czarny Staw two zones of copepod and rotifer occurrence can be named — in the metalimnetic zone the layer of highly variable and irregular oxygen conditions and the bottom layer with oxygen depletion during the winter stagnation. Both zones are separated by a thick layer of homothermic and homooxygenic water. The rate of exchange of zooplankters between the two layers must be rather high, but it shows no diel periodicity.

As the Zielony Staw is three times more shallow than the Czarny Staw the two zones are near each other. Most probably the small distance from surface to bottom is one of major factors improving the zooplankton productivity — the maximum biomass per unit area is here almost eight times greater than in the Czarny Staw. Undoubtedly the eutrophizing influence of the underground inflows of the Zielony Staw must be kept in mind, too. The zooplankton

density changes follow in the Zielony Staw a somewhat different course than in the Czarny Staw. Probably in the case of *C. tatricus* (Fig. 5) it stands in some connection with the bottom. In the Czarny Staw the density of mature individuals increases gradually from the moment of their appearance and reaches its maximum point relatively quickly. In the Zielony Staw on the other hand the growth is very rapid, followed by a gradual decrease and by another period of rapid growth (Fig. 4). During the period between the autumn and winter peak numbers the population of *C. tatricus* must have been present in the bottom water layers and perhaps as resting steages. However the sex ratio in the winter peak is different (40% males) from that in the autumn one (females exclusively). The only logical explanation of this is that part of the population appearing in the second period must have survived from the nauplii born in the previous summer.

Owing to this possible ability to live and feedon the bottom organic material and to its ability to tolerate low oxygen concentration* as well as to its eurythermic character**, *Cyclops tatricus* KoŻM. shows a wide range of geographical distribution; this is why it is so successful in lakes where trophic conditions for pelagic organisms are poor.

LONG-TERM CHANGES IN ZOOPLANKTON ASSOCIATIONS

Unpublished data of OLSZEWSKI on the 1949/50 winter stratification show that the zooplankton of the Zielony Staw was then much more rich. Table II presents mean densities of Cladocera and Copepoda (mean for the whole water column section) at this time and, for comparison, mean densities in the same period of 1962/63. The vertical distribution of copepods in 1949/50 was similar to that observed by me, densities reached 250 individuals per liter. Cladocerans were distributed evenly throughout the water column.

During the 13 years that did elapse the zooplankton density dropped and the number of species diminished markedly, too. The cladocerans disappeared almost completely, and of the former two species of copepods one (*Eucyclops serrulatus* FISCH.) was found again once only in a quantitative sample. Four crustacean species*, reported from the Zielony Staw by WIERZEJSKI (1884), LITYŃSKI (1913) and MINKIEWICZ (1912, 1917) were not encountered at all. A similar reduction in number of species took place in the Czarny Staw. Both in the Czarny Staw and in the Zielony Staw relatively high numbers of two cosmopolitan rotifers were found in the present study (*Polyarthra dolichoptera* IDELSON and *Keratella quadrata testudo* (EHRBG.). It seems probable

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* Our results confirm the data of RUTTNER (1938), who reported from the meromictic Hüttensteinersee (elevation 579m) maximum density of *C. tatricus* ("*C. strenuus*") females at 20m depth, where oxygen was 0.7 mg per liter.

** RYLOV (1948) expressed the opinion that *C. tatricus* is a stenothermic species characteristic of cold waters. Still, this copepod does equally well in rather warm lakes at the foot of the Alps (BALDI 1931, KOŹMIŃSKI 1933).

* 1. *Acanthocyclops vernalis* (FISCH.) = *Cyclops elongatus* CLAUS (WIERZEJSKI = = *Cyclops vernalis* FISCH. (MINKIEWICZ); 2. *Acanthocyclops virdis* (JURINE) = *C. brevicornis* CLAUS (WIERZEJSKI) = *C. viridis* JURINE (MINKIEWICZ); 3. *Daphnia pulex* DE GEER = *D. pennata* O. F. MÜLLER (WIERZEJSKI) = *D. Wierzejskii* LIT. (LITYŃSKI et MINKIEWICZ); 4. *Acroperus harpae* f. *frigida* EKM. = *A. leucocephalus* BAIRD (WIERZEJSKI) = *A. harpae* var. *frigida* EKM. (MINKIEWICZ).

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that these high rotifer densities result from the changes in crustacean plankton because in other Tatran lakes, where the cladocerans abound, the rotifers are sparse (valley Pięć Stawów Polskich — WOŻNICZKA 1964).

These community changes are most likely to be the effect of stocking with fish the lakes which, formerly were fishless (GLIWICZ 1963). Czarny Staw was stocked from 1881 on with fry of at least six species of Salmonidae. Zielony Staw was stocked with *Salvelinus fontinalis* (MITCH.)* only in 1950, i.e. after the studies of OLSZEWSKI.

Table II

Average numbers of Copepoda and Cladocera during winter stagnations 1949/50 (selected from unpublished data of Olszewski) and 1962/63 in the Zielony Staw *

			Date	3. I	22. I	14. II	1. IV	28. IV
1 9 5 0	Average number (ind. per liter) of		Cladocera	7.5	?	2.1	1.6	3.5
			Copepoda	14.0	15.0	111.5	132.0	109.0
			Date	2. I		20. III	16. IV	
1 9 6 3	Average number (ind. per liter) of		Cladocera	0		0	0	
			Copepoda	6.5		29.0	9.3	

* Including 2.5 individuals per liter of *Holopedium gibberum* Zaddach.

The survival and abundance of copepods and the extinction of cladocerans seem to be of complex nature. Perhaps the different vagility of the organisms in question played some role — cladocerans being larger and less mobile could more often fall prey to the trout. Another probable cause is that perhaps the eggs of *Cyclops tatricus* are resistant to the digestive enzymes of trout**.

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* The trout *Salvelinus fontinalis* (MITCH.) is believed to take readily allochthonous food (GĄSOWSKA 1962) but during the 7 months of winter stagnation, when the thick ice cover cuts the lake off the surrounding terrain it has to live on autochtonic fauna. Examination of the contents of alimentary canal of trout fished in April 1963 confirmed this view. It was found that the main food item was *C. tatricus*. Insignificant numbers of Tendipedidae — *Heterotrissocladius marcidus* (WALK.) and of bivalves — *Pisidium obtusale* C. PFR. were found, too. These two species inhabit the more shallow parts of the lake which the rather high oxygen supply makes accessible for the trout, known for its high oxygen requirements.

** Eggs found in numbers in the stomach and gut of *S. fontinalis* did not visibly differ from those taken from egg-sacs of females caught in the lake. It seems possible that the eggs may pass the alimentary canal of trout undamaged and subsequently undergo normal development. The ratio of number of eggs found in the alimentary canals (up to 19000 per fish) to the number of mature copepods (up to 1550 individuals per fish) is about 12 : 1 on the average. As at this time mean number of eggs

But what is important for their survival is the pattern of vertical distribution of copepods, because the highest densities of nauplii and of mature *C. tatricus* are found in the near-bottom water layers, inaccessible to the trout because of low oxygen values. The copepodits spend all the time of their development in the bottom deposits, still less accessible to the trout.

The cladocerans, on the other hand, were spread evenly throughout the volume of water (OLSZEWSKI, unpublished) or displayed high densities close to the surface (Fig. 10) thus being within easy reach of the fish.

The only cladoceran that was relatively numerous in 1962/63 — *Holopedium gibberum* ZADDACH — withstood the trout feeding upon it only to a limited extent. Thus the winter pulse of *H. gibberum* noted by OLSZEWSKI in 1949 (Table II) was not observed again. The summer pulse remained not destroyed presumably because of the allochthonous trout food, abounding when the lake was not ice-covered.

The enormous increase of the cosmopolitan rotifers whose numbers were formerly rather low (MINKIEWICZ 1917)* seems to result from the destruction of cladocerans i.e. from disturbing the equilibrium between the two competing filtrator groups. Similar examples when destruction of big zooplankters induced rapid increase in number of small ones were observed in fish ponds (HERBAČEK 1958, RYBAK 1962 and GRYGIEREK 1962).

5. SUMMARY

Zooplankton density in two alpine, oligotrophic lakes of the Tatra Mts., Poland, in relation to the thermal and oxygen conditions was studied. Samples were collected from April 6, 1962 till April 16, 1963 in the lakes Czarny Staw and Zielony Staw in the valley Dolina Stawów Gąsienicowych.

Both lakes are holomictic, with long spring and fall turnovers and a very short (1.5—2.5 month) summer stagnation. The winter oxygen depletion in the bottom water layer (micromeroeutrophy) is characteristic.

The dominant species (*Cyclops tatricus* KOŹM., *Keratella quadrata testudo* (EHRBG.) and *Polyarthra dolichoptera* IDELSON) have low oxygen requirements. They occur mainly in two zones, viz. the metalimnetic zone and the bottom water layer where in winter oxygen is lacking. It is worth particular attention that both these maxima fall at the zones of extremely diverse and unstable temperature and oxygen conditions. The zooplankters gather near the bottom thus implying that they are capable of using the bottom food resources. Highest densities are observed during the short summer stagnation period. *Cyclops tatricus* KOŹM. is monocyclic in these lakes, but the development periods of particular individuals are largely dispersed in time. The distribution of copepods and rotifers is patchy; vertical distribution found in one water column is not representative of the whole reservoir.

The numbers of crustaceans, esp. of cladocerans, has declined greatly since 1949 whereas the rotifers increased very much in number. Both phenomena are probably due to stocking the lakes with Salmonidae.

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per egg-carrying female *C. tatricus* is 17.35 eggs it has to be concluded that *S. fontinalis* selects the egg-carrying females. (Out of the above values it can be computed that in trout alimentary canals the egg-carrying females made 72% of total copepod number, whereas they made only 18% of the *C. tatricus* population at that time). The egg-carrying females are most probably selected as being bigger and less mobile.

* *Polyarthra dolichoptera* IDELSON, called by MINKIEWICZ (1917) *P. platyptera* EHRBG. and *Keratella quadrata testudo* (EHRBG.), called by MINKIEWICZ (1917) *Anuraea aculeata* EHRBG.

6. STRESZCZENIE

Celem pracy jest analiza stosunków ilościowych w zooplanktonie dwóch wysokogórskich zbiorników oligotroficznych na tle przemian termiczno-tlenowych. Materiały zbierano w okresie od 6.IV.1962 do 16.IV.1963 na Czarnym Stawie i Zielonym Stawie w Dolinie Stawów Gąsienicowych.

Oba zbiorniki są jeziorami holomiktycznymi o długotrwałej cyrkulacji wiosennej i jesiennej oraz o bardzo krótkim, 2—3-miesięcznym okresie stagnacji letniej. Każdego roku w zimie tworzy się w obu zbiornikach charakterystyczna warstwa odtlenionej wody przydennej (mikromeroeutrofia).

Dominujące gatunki zooplanktonu (*Cyclops tatricus* Koźm., *Keratella quadrata testudo* (Ehrbg.) i *Polyarthra dolichoptera* Idelson) charakteryzują się niewielkimi wymaganiami tlenowymi. Występują one w badanych zbiornikach głównie w dwóch strefach: w warstwie skoku termicznego i warstwach naddennego gradientu tlenowego. Gromadzenie się organizmów zooplanktonowych przy dnie sugeruje, że zooplankton obu zbiorników może bezpośrednio wykorzystywać pokarmowe zasoby osadów dennych.

Szczyty liczebności gatunków dominujących przypadają na krótki okres stagnacji letniej. *Cyclops tatricus* Koźm. jest w tych zbiornikach gatunkiem monocyklicznym, z tym że okresy rozwoju poszczególnych osobników w populacji są względem siebie znacznie przesunięte w czasie.

Rozmieszczenie widłonogów i wrotków wykazuje w obu zbiornikach wyraźną mozaikowatość; pionowe rozmieszczenie zooplanktonu stwierdzone na jednym stanowisku nie jest więc reprezentatywne dla całego zbiornika.

Znaczne zubożenie jakościowe i ilościowe skorupiaków, głównie wioślarek, oraz masowy rozwój wrotków w tych zbiornikach w okresie od 1949 do 1962 roku jest zapewne wynikiem zarybienia.

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A RECORDER FOR MEASUREMENT OF WAVES IN LAKES

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ABSTRACT

A wave recorder is described which permits the analysis of single waves and gives a general picture of the intensity of wave oscillation in a given area.

The paper includes examples of records and analysis of the wave oscillations for Lake Mikołajskie during the summer of 1961.

CONTENTS

1. INTRODUCTION

The character of all lakes is, to a considerable extent, shaped by the intensity of the wind action. This fact is reflected in a different extent to which the water is mixed in lakes (Hutchinson 1957, Wiszniewski 1953).

The majority of authors of works in which the effect of wind is dealt with examine the denivellation phenomena and superficial seiches (Karaušev 1960). Mortimer 1962), related with these phenomena, as well as their biological consequences (Colebrook 1961, Thomas 1950). Shaping of the thermal balance of lakes (Birge 1916) and of the intensity of matter circulation (Findenegg 1937) is ascribed to the influence exerted on the lake by the wind but they are rather a factor, causing the formation of currents, evoked in the lake by the influence of the wind. In these works, the problem of influence waves has usually been omitted by the authors. It was only recently that waves as a factor forming the circulation in lakes have been referred to by Patalas (1960) who, on the basis of formulas derived by Andrejanov, calculated the theoretical magnitude of waves.

Works, published so far, has been hydrological in character (for instance, those by Ajbulatov et al., 1962) and the limnological and, especially, the hydrobiological aspects have not been examined. In very few works have the authors dealt with waves as a factor, influencing biological phenomena and these few works are mostly qualitative in character. A detailed analysis of the influence exerted by waves on the occurrence of larvae of *Molanna angustata* Curt. was carried out by Grębecki, et al. (1954) who used Andrejanov's formulas and did not measure the actual magnitudes of waves. The omission of waves from hydrobiological works results mostly from the considerable difficulties involved in taking measurements.

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Single measurements of waves, taken together with a biological sample, yields haphazard results which cannot be interpreted. Continuous measurements require either a permanent observation post, or the installation of a wave recorder.

The wave recorders, now in use, have been constructed for hydrological purposes and for recording all parameters of a single wave. They are, therefore, high-speed instruments for a brief period operation and cannot be used longer observations without special analyzers (such as, for instance, that which analyzes a record by resolving it into Fourier's haromonics).

The present paper contains a description of a diurnal recorder of the wave intensity.

2. CONSTRUCTION AND WORKING PRINCIPLES OF THE INSTRUMENT

Two variants of a wave recorder have been worked out. Both are based on the same principle and they differ only in the type of mechanism which operates them.

The working principle consists either in a transformation of the wave movement of the water surface into the movement of a recording tip which marks a trace on the surface of a chart paper, shifted by a clock-work (variant 1), or in changing the position of the paper proportionally to the magnitude of waving while the recording tip is shifted by the clock-work (variant 2).

The choice of the variant depends on which type of the recorder we would like to adapt to our purposes. In variant 1, a clock-work, used in thermographs has been applied, while in variant 2, a limnigraph of the "Valday" type has served as a basis.

Variant 1 (Fig. 1) is built as follows. A roller, with a clock-work (a) mounted in it, revolves and, at the same time, moves the paper ribbon which thus passes under the recording tip (b.) The recording tip is fastened to a steel string, embracing grooved wheels (c and d). The wheel (c) is mounted on a common axis with a grooved wheel (e) over which a string is thrown, fastened to a float (f) and kept tense by a weight tied at its other end (not shown in Fig. 1). The vertical movements of the float, evoked by waves, cause the revolving movement of the wheels (e) and (c), coupled with each other.

The ratio of the circumferences of both wheels (c and e) should be so calculated as to avoid the possibility of slipping the recording tip off the paper ribbon which otherwise might be caused by the maximum wave expected. To assure vertical movements only of the float, it should be placed between two rails, made of wire and kept tense by a weight (g), suspended from them.

Variant 2 (Fig. 1) of the wave recorder for whose construction the mechanisms of the "Valday" limnigraph have been used is much simpler. The adaptation consists only in replacing the bucket pen with the recording tip and in the appropriate choice of the grooved wheel so as the expected maximum wave could not cause a full turn of the wheel together with the roller, coupled with it. As in variant 1, the float of the waving recorder is placed between two wire rails so as to prevent its side movements. After the adaptation, the instrument consists of the following parts, performing the following operations. The roller (a), coupled with the wheel (e) revolves proportionally to the height of waves. The recording tip (b) is moved along
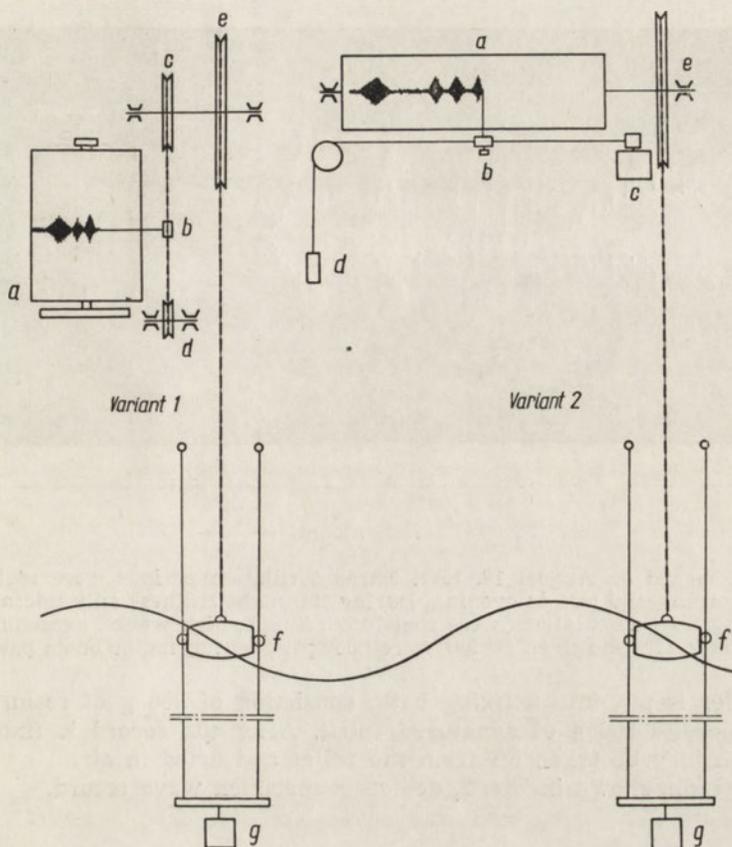
Fig. 1. Structural scheme of the wave recorder (details in text)

the generating line of the roller by the clock-work (c), driven by the weight (d). The float (f) transmits the movements of waves to the grooved wheel (e). The horizontal movement of the float is limited by two wire rails stressed by the weight (g), suspensed from them.

Due to the character of the operation of the recorder, it has been necessary to change the manner of recording. With the wave height of 30 cm, wave period of 3 sec. and transmission ratio of 1:2, the bucket pen of the recorder would daily draw a line 17.280 m long and, therefore, it should have a giant reservoir filled with ink and, moreover, since a line about 5 μ thick would be drawn, with such a period of oscillations and such speed of the pen roller travel, the ink would be smeared all over the paper.

For this reason a recording tip and a smoked, soot coated, paper have been used for this purpose. The recording tip, moving along the surface of paper, takes the soot from it and leaves a distinct trace. To smoke the paper, it is best to revolve the roller with a paper ribbon, put on it, over the flame, produced by burning turpentine or petroleum. When the paper is sufficiently smoky, the roller should be cautiously mounted in the recorder. After record-
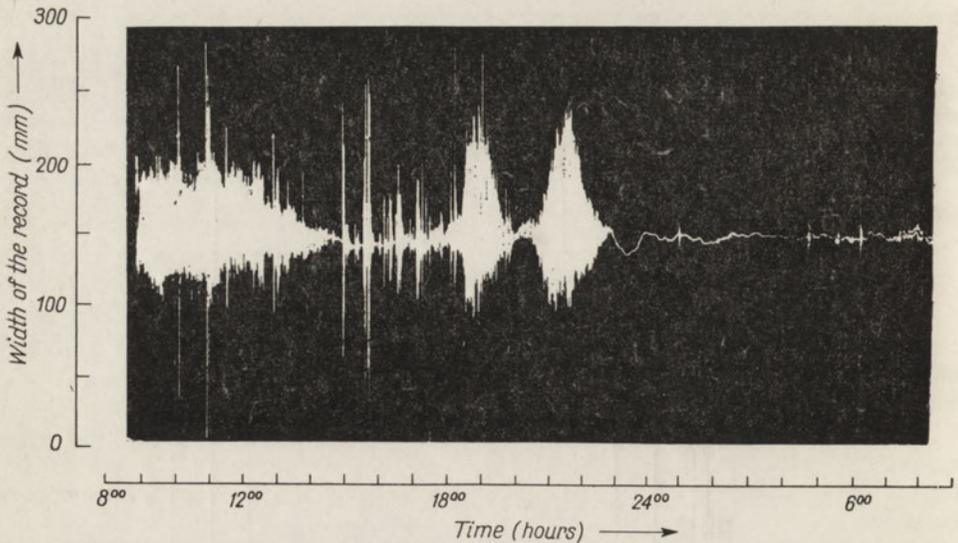
Fig. 2. Wave record on August 19, 1961. Three oscillation periods were registered: one in the morning and two at evening. During the night stillness only micro-sejche types of water level fluctuations were registered. Single, high waves, exceeding over average oscillation for the given period, were brought about by motor boats passing by

ing, the roller is put into a fixing bath, consisting of 250 g of rosin, 100 g of turpentine and 500 g of denatured spirit. After the record is fixed, the paper ribbon may be taken off from the roller and dried in air.

A photograph, shown in Fig. 2, depicts a specimen wave record.

3. ANALYSIS OF A RECORD

The following information may be supplied by the analysis of a record: (a) height and time of occurrence of a maximum wave; (b) time within which waves exceeded a definite magnitude; (c) intensity of waves at particular moments; (d) mean intensity of waves during definite periods; (e) energy of waves at a given time and place.

If the first three items of information may be directly read from the record on the paper ribbon, the two remaining data may be obtained only after appropriate calculations. In the first approximation, the energy of the wave is proportional to the square of its height. The energy of waving is, therefore, proportional to the wave height and to the wave duration. In calculating the mean wave height during a definite period (one hour is most convenient period for comparisons), the energy of waving may be subsequently calculated with an approximation sufficient for many purposes. The easiest method to calculate an approximate mean height of the wave during a given one hour period is to use the planimetry, that is, to determine the area of the record (in sq mm) for a given hour and to divide it by the number of mm per one hr, found on the axis of time. Another method is to divide the record into a series of regular geometrical figures and, subsequently, to calculate a weighted mean for the interval under study.

4. RECORDER LOCATION ON THE LAKE

As they move across a lake, waves change their properties, particularly near the shore and, therefore, the best site for the recorder depends on the nature of the information required.

In the case when the amount of wave energy is studied which, together with waves, reaches the littoral, the recorder should be so located as to expose its float to the action of nonmodified oscillations. Thus, for instance, the recorder must not be placed close to a larger vertical wall since the interference may take place of a usual and reflected wave and, consequently, a stationary wave may be formed which has different properties than those of the usual wave. Likewise, the recorder should not be located within the range of a coastal shelf where short waves are transformed into long ones which also are different in character. A pier supported by piles and reaching into the lake to a place outside the range of the coastal shelf is the most advantageous place to locate the recorder. The waves recorded by the instrument are not affected to any significant extent by the piles of the platform. The recorder should be placed on a part of the pier which projects furthest into lake.
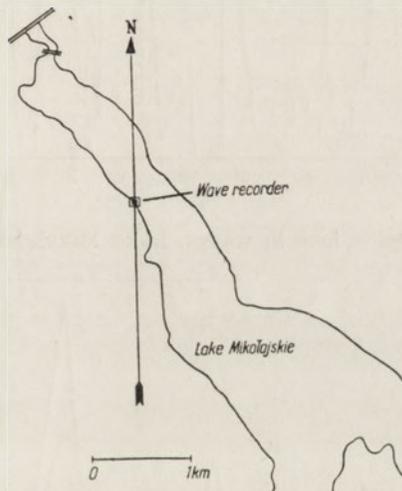

Fig. 3. Recorder location on the Lake Mikołajskie

The wave recorder, described in the present paper, has been installed on a pier near the Hydrobiological Station at Mikołajki 30 m from the shore. The depth of water in this place amounts to ca. 6 m. This pier is located on the western shore of Lake Mikołajskie. A topographical sketch (Fig. 3) allows one to determine the runways of waves, incoming from different directions. At this measurement point, the shore is almost parallel to the main axis of the lake. The situation of the measurement site is not very advantageous since the predominating, that is, western and north-western winds do not evoke waving in this point. The monthly resultant of the wind in June, 1961, has not been normal to the shore and was directed at 239°.

Similar conditions have been recorded in July (222°) and August (246°).
However, in the case of winds which blow from the lake towards the shore,
considerable oscillations may be observed.

5. ANALYSIS OF A SPECIMEN OF RECORD

Values for one hour oscillations during the period between June 11, and
June 25, 1961 are shown in Fig. 4. Although it presents the largest number
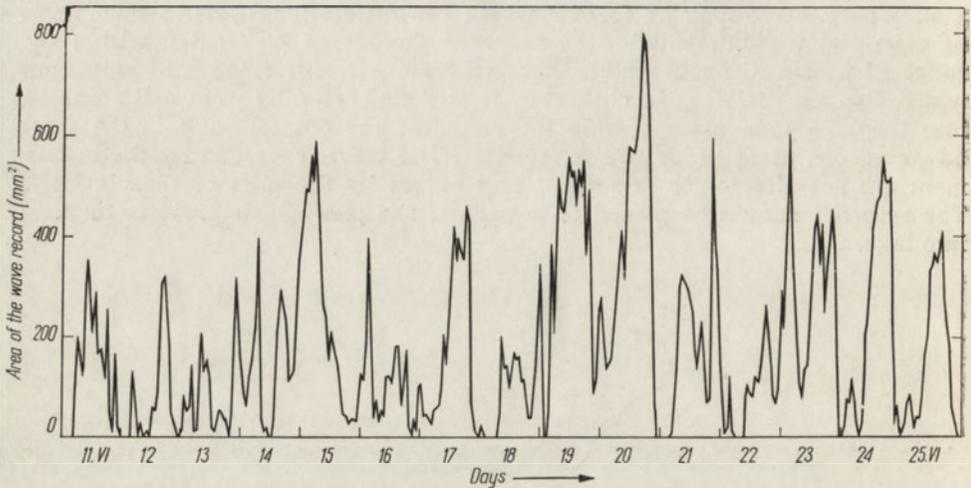of data, it is fairly difficult to interpret.
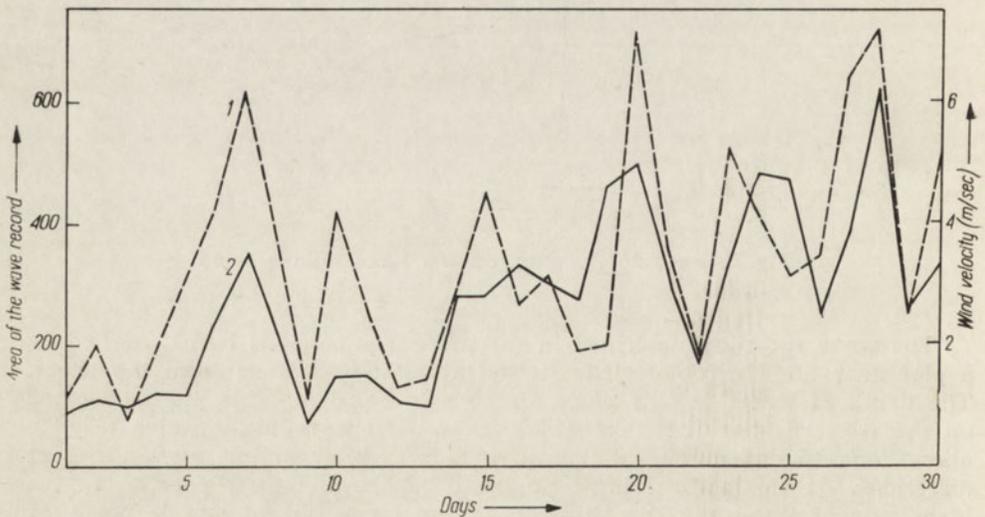

Fig. 4. One hour oscillations in waves. Lake Mikołajskie, 11—25.VI.1961

Fig. 5. Mean daily wave hights and wind velocities (unreduced directions) for June,
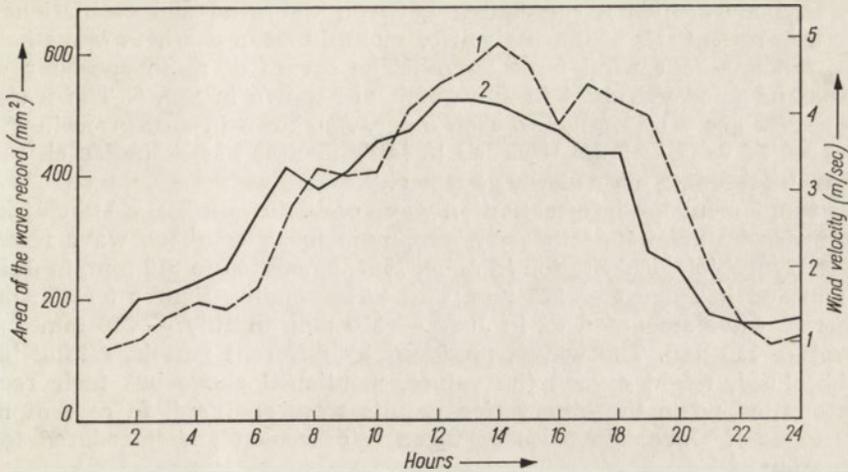1961; Lake Mikołajskie
1 — waves, 2 — wind

Fig. 6. Mean one-hour wave hights and wind velocities for June 1961; Lake Mikołajskie
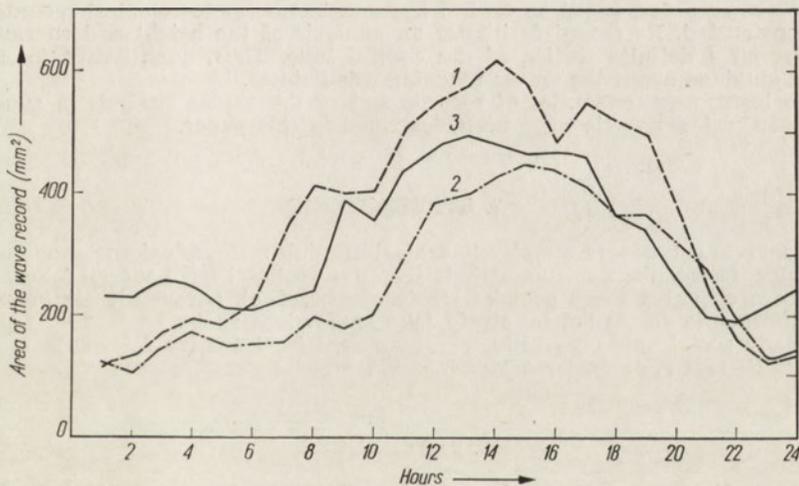1 — waves, 2 — wind

Fig. 7. Mean on-hour wave hights for June (1), July (2) and August (3), 1961; Lake Mikołajskie

The results of the analysis of oscillations recorded in summer of 1961 are presented below as an example.

The mean daily wave heights have been calculated from hourly readings. Although the magnitude of oscillations depends not only on the wind force but also on the fetch, that is, on the shape of lake, a fairly large degree of conformity is observed between the wind velocity and the magnitude of oscillations. A curve of mean daily wind velocities and a curve of mean daily wave heights, both of them drawn for June, 1961, are presented in Fig. 5. A similar trend in changes is displayed by both these curves.

A still more distinct correlation between the wind and oscillations can be stated on the basis of the analysis of monthly mean one-hour wave heights and mean one-hour wind force values. The curves of mean one-hour wave heights and wind velocities in June, 1961 are shown in Fig. 6. The traces of both curves are very similar to each other. As shown in a diagram in Fig. 7, the curve of wave heights recorded in later months has a similar character. This is, therefore, a more general regularity.

To supplement the information on wave oscillations in Lake Mikołajskie it should also be mentioned that the maximum mean one-hour wave recorded off the Hydrobiological Station in June, 1961, amounted to 270 mm, in July — 300 mm and in August — 225 mm. The corresponding figures for the maximum real wave amounted to, in June — 330 mm, in July — 370 mm and in August — 310 mm. The waves, produced by different vessels, sailing in the neighborhood, might exceed the values, mentioned above but their records were omitted when the observation results were analyzed. In case of need, these types of waves may also be taken into account and introduced to the elaboration.

6. SUMMARY

A wave recorder, based on typical hydrological or meteorological recorders, has been constructed. Its record facilitates an analysis of the height and energy waves which reach a definite section of the coastal zone. Thus, quantitative information may be obtained about the waves reaching this habitat.

The instrument, examples of records and of the waves analysis in summer of 1961 on Lake Mikołajskie have been described in this paper.

7. STRESZCZENIE

W oparciu o typowe samopisy hydrologiczne lub meteorologiczne skonstruowano rejestrator falowania. Zapis umożliwia analizę wysokości fali i energii falowania docierającego do określonego odcinka strefy przybrzeżnej. Otrzymuje się przez to istotne informacje dla badań tej strefy jako środowiska życia.

Podany został opis przyrządu, przykład zapisów i analizy falowania w miesiącach letnich 1961 r. na Jeziorze Mikołajskim.

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