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BRINE SHRIMP ARTEMIA IN WESTERN SIBERIA LAKES

NOVOSIBIRSK
"NAUKA"

To Dear Patrick
from the authors as
a sign of the greatest
respect and appreciation
for all help which you have done
for us and whith hope for fruitful
cooperation in the future.

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Ibaisro Elena

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АРТЕМИЯ В ОЗЕРАХ ЗАПАДНОЙ СИБИРИ

Ответственный редактор
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Translated from Russian by
A. Otarova, M. Korentovich, L. Litvinenko

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The monograph is written on the basis of studies carried out in the Siberian region from 1995 to 2004. The location of 83 Artemia lakes in huge territory from the Urals to the Altai and Sayan mountains, the characteristic of climate, lake morphometry, hydrology, hydrochemical classification of lakes are given in the monograph. Detailed description of biocenoses of salt lakes, including data on species composition of phytoplankton, zoobenthos and zooplankton and their productivity is presented in the paper. Functional dependence between number of species and index of water salinity is identified. The borders of occurrence of some species are determined.

The main part of monograph is devoted by the description of Artemia biology for populations from 47 surveyed lakes in Siberia (Tyumen region — 2, Kurgan — 24, Chelyabinsk — 7, Omsk — 2, the Altai region — 8, Khakasia — 2, Tuva — 2). The results of numerous morphometric studies are given. The annual dynamics of brine shrimp cysts and crustaceans number based on monitoring data, which were conducted in five lakes during 2000–2004 was detailed. The issues of functioning of the ecosystems of the lakes: phytoplankton and Artemia production, crustacean eating, Artemia role in purification of reservoir and others are shown separately. In the section on Artemia reproduction the information about parthenogenetic and rare bisexual populations is provided. For the first time for Siberian populations the data of cytogenetic studies and DNA analysis are given. The whole Chapter is devoted by the factors determining the density of crustaceans and the number of cysts. The problem of improving the quality of cysts associated with diapause is presented. The various ways of diapause interrupting are considered. In Conclusion, the data on long-term dynamics of Artemia cysts stock in Siberian region were conducted. Also a new method of brine srimp stocks determining, which was developed in cooperation with Belgian and American scientists, is discussed.

The book is for ecologists, hydrobiologists, fish farmers, experts in the use of natural resources and environmental protection, teachers and students of High Education Schools.

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INTRODUCTION

Western Siberia is rich by shallow, hydrochloric reservoirs, which fauna is frequently presented by only brine shrimp *Artemia* genus. The uniqueness of these crustaceans is their high adaptation to adverse factors. In an environment where other animals can't evolve, Artemia "thrives" in monoculture. Scientific interest to these organisms is due to their exceptional osmoregulation ability, a variety of physiological, biochemical and morphological properties of individual populations, the existence of polyploidy which is a very rare phenomenon in the animal world. Artemia shrimps are used in toxicological experiments as test-objects. In addition to scientific interest, Artemia have practical value. Cysts of brine shrimps, from which you can get nauplii at any time, are worldwide recognized as the best live starter feed for fish larvae and crustaceans. The commercial value of these shrimps related to the fact that Artemia cysts can form commercial accumulations.

For more than a century study of these organisms the interest to them has not abated. The area of brine shrimps has increased considerably: in addition to the natural migration routes (migratory birds), people have introduced them artificially in reservoirs (for example, when people produce salt).

In Western Siberia the study of Artemia was started in 70s of XX century. The investigations were conducted mainly on the lakes of the Altai territory. Wide area from the Urals to the Altai was not studied practically.

In this book we will try to fill this gap and to present not only the biogeography of species, but, if it is possible, all the theoretical and practical studies on the mechanisms of the development of Artemia populations, as well as issues of environmental protection measures.

GLOSSARY

Amplification — DNA copy.

Artemia cysts (diapausing eggs) — Artemia embryos covered with a thick shell under gastrula, formed both in summer and in autumn periods and characterized by high resistance to environmental conditions and prolonged diapause.

Artemia cysts dehydrated in brine — cysts located in brine and having humidity 20–50 %.

Cytochrome — mitochondrial protein involved in electron transport chain.

DNA fingerprinting — genetic fingerprinting.

DNA profile (pattern, band) – the bands on foregram corresponding to individual segments of DNA.

Dry cysts of brine shrimps — dried (dehydrated) in the air and having humidity less than 10 %.

Electrophoregram — photograph of the obtained DNA profiles.

Electrophoresis — a method of separating DNA-molecules in an electric field.

Fishing season — the period of time when the harvesting of aquatic organisms (cysts of brine shrimp) is allowed in a certain area with help of certain fishing gears.

Generation — the group of individuals in population with the same degree of cognation in relation to common ancestors, i.e. the direct offspring of individuals of the previous generation.

Growing season — the period of time from the middle of April to the middle of October, it is nearly 180 days for Artemia brine shrimps; for planktonic and benthic cysts this time is from June (the beginning of laying crustacea cysts) till November.

Hatching of Artemia nauplii — release of nauplii from the shell of cysts. Under optimal conditions (temperature 23–28 °C, illumination 1000–2000 Lux; NaCl = 5–35 g/l; $NaHCO_3$ — 2 g/l; aeration; pH = 8.0–8.5) usually hatching occurs after 20–24 hours.

Hydrated cysts of brine shrimp — cysts with water content of more than 50–60 %. Full hydration of cysts occurs after two-hour keeping of cysts in fresh water.

Litter — the set of descendants, they were born by the same female in one time.

Nauplii, juveniles, preadults and adult individuals — different age groups of brine shrimps:

— *nauplii* (nauplial and metanauplii periods) are characterized by the appearance of the body segmentation, beginning the exogenic feeding and the ability to filter out particles of food (usually they have dimensions from 0.5 to 3.0 mm);

— *juvenile crustaceans* (post-nauplial period) are characterized by elongation of the abdomen and torso, the advent of thoracic legs, the development of lateral compound eyes (conditionally accepted length is from 3.1 to 6.0 mm);

— *preadult crustaceans* (post-larval period) are characterized by the presence of rudimentary genital structures which allow to distinguish future males from females (normal length is between 6.1 to 8.0 mm);

— *adult crustaceans* have well-developed sexual characteristics: females have egg sack (ovisac), males have copulatory organ and hook head grasps (normal length is from 8.1 up to 12.0 mm).

Nucleotide — a monomer of DNA, consisting of nitrogenous base, sugar and phosphoric acid residue.

Population — a set of individuals of one species possessing common gene pool, occupying a certain territory and reproduces itself over a large number of generations.

Primer — nucleotide sequence.

Quota — share of total allowable catch (TAC) of aquatic organisms (for example: cysts of brine shrimps), distributed between specific suppliers.

The eggs of brine shrimp — Artemia embryos coated with a thin shell, formed by females during the summer period and characterized by a brief diapause.

Total allowable catch (TAC) — a research-based value of commercial withdrawal of hydrobionts (Artemia cysts or biomass) corresponding to the current state of stocks and determining the strategy of exploitation aimed at sustainable fisheries.

Total reserves of brine shrimp cysts — total number (biomass) of cysts located in plankton, benthos, female ovisacs and coastal clusters.

Weight of Artemia crude cysts — mass of living (native) cysts after dehydration in the conditions of reservoir and having humidity 50–60 %. Index of conversion from wet to dry weight depends on the moisture of collected cysts and conditionally accepted equal to 2.

LIST OF ABBREVIATIONS

al — the length of abdomen
aw — the width of abdomen
B — biomass
BOD_5 — biochemical oxygen demand for 5 days
bp — base pairs
C — ration
c/a — ratio of the length of cephalothorax to the length of abdomen
COI — cytochrome oxidase I
COXI — cytochrome oxidase XI
C_v — coefficient of variation, %
de — the distance between eyes
DNA — deoxyribonucleic acid
ed — diameter of eyes
F — average population indicator of Artemia female fertility
f/a — the length of furca to the length of abdomen, %
F_c, F_{eg}, F_n — average population indicators of number of cysts (*c*), eggs (*eg*) and nauplii (*n*) in female ovisacs, respectively
fl — the length of furca
fw — the width of furca
hw — the width of the head
la — the length of the first antenna
LAC — limited allowable concentration
lim — limit value of parameter
N — the number of organisms
m — error mean (standard error)
M — mean
max — maximum value of parameter
min — minimum value of parameter
mtDNA — mitochondrial DNA
n — number of measurements (sample size)
N_f/N_{avr}, B_f/B_{avr} — the ratio of actual indices of abundance and biomass to mean seasonal
P — production

p — significance level, reliability
PCR — polymerase chain reaction
PO — permanganate oxidation
r — coefficient of correlation
R — waste on exchange
R^2 — coefficient of determination
ra — the ratio of the length of abdomen to the total body length, %
RAPD — amplification of polymorphic DNA
R_s — Spearman's coefficient of correlation
S — the area of the lake
sf-l — number of setae on left furca
sf-r — number of setae on right furca
t — normalized deviation, Student's Test
tl — the length of the body
UPGMA — dendrogram of similarity
σ — the standard deviation
$\sum_i$ — the sum of ions
♀ — female
♂ — male

Chapter 1

BIOLOGICAL FEATURES OF ARTEMIA

1.1. Systematic position

In systematic relation Artemia, Leach 1819 genus refers to phylum Arthropoda, subphylum — Crustacea, class — Branchiopoda, order — Anostraca, family — Artemiidae. Artemia species has not been fully elucidated. Previously authors thought that there was only one species *Artemia salina* (Linn.) and there were numerous Artemia races which were different from each other morphologically. Those races were combined into two groups due to their way of reproduction: bisexual or zygogenetic (with males and females) and parthenogenetic (only females). Parthenogenetic races, in turn, were differed by their chromotype: diploids, triploids, tetraploids, pentaploids and even decaploids (Persoone, Sorgeloos, 1980). However, due to geographic isolation of Artemia habitats theoretically there was a possibility of existence for different species. Later researches confirmed that fact. Experiments in breeding revealed to find reproductive isolation of certain geographical races (Barigozzi, 1974; Clark, Bowen, 1976; Bowen et al., 1978), which made the possibility to distinguish the following species:

— *A. salina* Linnaeus 1758 (reservoirs of England and the Mediterranean) = *A. tunisiana* Bowen and Sterling 1978 (reservoirs of North Africa);
— *A. urmiana* Gunther 1900 (water bodies of Iran);
— *A. sinica* Yaneng 1989 (reservoirs of Central and Eastern Asia);
— *A. persimilis* Piccinelli & Prosdocimi 1968 (reservoirs in Argentina);
— *A. franciscana* with two subspecies: *A. franciscana franciscana* Kellog 1906 (reservoirs in America, the Caribbean and Pacific Islands); *A. franciscana monica* Verrill 1869 (Mono Lake in the USA, California reservoirs);
— *A. tibetiana* Abatzopoulos, Zhang and Sorgeloos 1998 (lakes of Tibet);
— *A. species* Pilla and Beardmore 1994 (the reservoirs in Kazakhstan).

Biochemical, cytological and genetic studies conducted later (Abreu-Grobois, 1987; Pilla, 1992; Pilla, Beardmore, 1994; Gajardo et al., 2001a, b, 2002; Baxevanis et al., 2004; Bossier et al., 2004) confirmed dissociation of selected species.

Parthenogenetic races, which had not been not identified to species, were decided to unite in one common group of indeterminate species: *A. parthenogenetica* (reservoirs of Europe, Africa, Asia, Australia) (Barigozzi, 1974; Bowen, Sterling, 1978).

In reservoirs of Russia Artemia is not identified to species. Therefore it would be correct to use for bisexual races only the designation of the genus *Artemia*, and for parthenogenetic — *A. parthenogenetica*. At present time to identify Russian populations all methods of modern science, including morphometric, biochemical, karyological studies and DNA analysis are attracted (Boyko, Litvinenko, 2004; Boyko et al., 2005; Boyko, Litvinenko, 2006; Boyko et al., 2004).

The fact about *Artemia* exceptional plasticity has been known for a long time. In 1875 Artemia ability to change shape and size under the influence of different salinity was marked by V.I. Shmankevich (1875). Indeed, depending on the salinity Artemia forms different morphological races which differ in body size, the ratio of the length and width of abdomen and structure of furca. This feature of Artemia was taken as the basis for the allocation of four varieties (cit. on: Solovov, Studenikina, 1990): *Artemia salina* var. *mulhausenii* Fisher, *A. s.* var. *arietina* Fischer, *A. s.* var. *principalis* Simon, *A. s.* var. *koppeniana* Fisher. However, the classification of varieties has not been accepted by abroad scientists.

Identification of Artemia species is very complex and it is based on the use of morphological, karyological, genetic and biochemical methods in conjunction with definition of reproductive characteristics.

Species *A. tibetiana* is well-insulated in morphological term. The sizes of cysts of this species are the biggest and reach 330 μm (Abotzopoulos et al., 1998, 2002). The smallest sizes of cysts (average 220–250 μm) are found in three species: *A. tunisiana* (*A. salina*), *A. persimilis* and *A. franciscana*. Species *A. sinica* has a little bit larger sizes of cysts (about 255 μm). Two other taxons: *A. urmiana* and *A. parthenogenetica* have similar sizes of cysts (280–290 μm). All these differences are also for nauplii because between the sizes of cysts and nauplii there is a strong direct correlation (Vanhaecke, Sorgeloos, 1980). Nauplii stage I (Instar I) for the most Artemia species and populations have the length in the range 400–500 μm, excluding nauplii of *A. tibetiana*, which length reaches 667 μm (Abotzopoulos et al., 1998). The body length of polyploid adult crustaceans is also higher than diploid ones. However, the sizes of adult mature crustaceans vary greatly within the same species and they depend more from external environmental factors (salinity, temperature and others) than from genotype. Therefore, this feature cannot be taken as the basis for species identification.

The use of scanning electron microscope has allowed to identify some taxonomic characters separating the populations from the other species of genus (Triantaphyllidis et al., 1997a, b; Mura, 2004; Mura, Nagorskaya, 2005): for *A. salina* (*tunisiana*) — the absence of a tubercle at the base of male's penis; for *A. urmiana* — the presence of ectodermal bumps in female's brood chamber.

The features concerning the form of frontal tubercles (Triantaphyllidis et al., 1997a, b; Mura, 2004) and mandibles (Mura, 2004) were not valuable sufficiently because their variability was high.

1.2. Evolution of *Artemia* genus

Artemia is one of the best representatives of aquatic organisms, helping to fill gaps in the knowledge of evolutionary and comparative biology of arthropoda (Marco et al., 1991). Stressing the importance of this organism for the study of evolution, some authors (Abreu-Grobois, Beardmore, 1982; Marco et al., 1991) call Artemia "Water Drosophila". In fact, Branchiopoda have been living from the Devonian period (about 410 million years ago). Artemia is descended from an ancient ancestor who lived in the Mediterranean region (Abreu-Grobois, Beardmore, 1982; Abreu-Grobois, 1987). At that time, according to geological indicators, it was the only place in the world, where the highest salinity which was necessary for Artemia prosperity took place (Abreu-Grobois, 1987). The hypothesis that the Mediterranean was the center of Artemia spread is evidenced by the variety of Artemia types, which were found currently in this area, the simultaneous existence of parthenogenetic and bisexual races, diploidy and polyploidy (Gajardo et al., 2002). Then Artemia spread all over the World. Approximately 25 million years ago the division of populations of the Old World and New World happened. It is believed that *Artemia persimilis* is the most primitive species which is more closely related to the original ancestor (Perez et al., 1994; Badaracco et al., 1995; Gajardo et al., 2002). Currently this species has a restricted area (Argentina). This is the only species with diploid set equal to $2n = 44$. Approximately 10–12 million years ago the separation of species of the New World (*Artemia franciscana* and *Artemia persimilis*) occurred.

The occurrence of parthenogenetic populations from bisexual (line *Artemia salina*) occurred about 5.4 million years ago (Abreu-Grobois, Beardmore, 1982; Perez et al., 1994). The antiquity of Artemia parthenogenesis, according to the researchers (Gajardo et al., 2002), does not correspond to that is observed in other species of invertebrates and vertebrates, where asexual reproduction is very rare and more modern. The preservation of this type of reproduction in populations of the Old World and the absence in populations of New World causes interest from an evolutionary point of view.

Artemia dwells mainly in continental hyper salty waters and rarely in marine estuaries with salinity, as a rule, higher than sea water. Between Artemia populations of the Old and New World for gene flow there is a geographic barrier in the form of oceans. Strict isolation, however, is absent because Artemia cysts can be spread by waterbirds around the world. However, hyper-saline waters of the New World (North and South America) are the natural habitat for two species of brine shrimp: *Artemia franciscana* and *Artemia persimilis*. In the Old World these species occur only as a result of human activity, mainly for Artemia cultivation at the enterprises for production of salt. Geographical and possibly migration barriers to gene flow between European and Asian populations are absent. However, reproductive isolation exists and this is evidenced by the presence of both parthenogenetic and bisexual populations of Europe (*Artemia tunisiana* = *A. salina*) and Asia (*A. sinica*, *A. urmiana*, *A. tibetiana*, *A.* sp.).

Parthenogenetic populations of brine shrimps, according to morphological (Hontoria, Amat, 1992; Triantaphyllidis et al., 1997b), cytological studies, as well as allozyme analysis of proteins (Abreu-Grobois, Beardmore, 1982; Abreu-Grobois, 1987; Abatzopoulos et al., 1993) show a large variety of clones. Parthenogenetic populations have different levels of ploidy (diploids, triploids, tetraploids, pentaploids). It is believed that polyploid genotype resists stress and environmental influences better. This explains the distribution of brine shrimp populations in conditions of considerable fluctuations in temperature and salinity.

In the literature the fact of genetic and morphometric differentiation between populations of the New World and Old World is covered quite extensively (Abreu-Grobois, 1983, 1987; Pilla, Beardmore, 1994). Thus, genetic distance according to Nei (1972) between these populations, based on a study of 20 protein loci has a range from 0.74 to 1.5, and between populations of the Asia is from 0.005 to 0.36.

Relatively weak genetic differentiation among Asian populations requires validate the existence of species *A. sinica*, *A. urmiana*, *A. tibetiana*, *A.* sp.

Thus, identification of Artemia species has not been finished yet, especially there is a lot of uncertainty in respect of parthenogenetic and bisexual populations of the Asian continent. Therefore, it is necessary to continue researches as field as in the Lab, using morphological, karyological, biochemical and genetic methods of analysis.

1.3. Distribution in the World

Halophilic branhiopoda crustaceans of the genus *Artemia* are spread all over the World from offshore waters till continental hiper salty lakes. The only continent where they do not occur is Antarctica. The area of these crustaceans is confined to arid and semi-arid climatic zones. Geographically brine shrimp reservoirs are located between 56° North and 55° South latitude.

The list of Artemia reservoirs is updated constantly. So, if at the beginning of XX century it was reported about 80 Artemia reservoirs located in 21 countries (Abonyi, 1915), whereas by 1980 it was discovered 244 natural Artemia habitats (Persoone, Sorgeloos, 1980). In the lists presented later (Sorgeloos et al., 1986; Vanhaecke et al., 1987) it was recorded, respectively, 332 and 362 natural reservoirs; 26 lakes were in the former USSR, including 6 reservoirs in Siberia.

Ten years later in summaries of G. van Stappen (Van Stappen, 1996) and Triantaphyllidis with co-authors (Triantaphyllidis et al., 1998) there were nearly 500 natural Artemia habitats, 15 lakes of them were mentioned in Siberia.

The latest researches of G. van Stappen (Van Stappen, 2002) are described 600 *Artemia* habitats, located on the territory of 66 countries. In the study it is mentioned about 18 Siberian lakes (Fig. 1). In Fig. 1 it is shown the location of brine shrimps in the world (Van Stappen, 2002), including our data in Siberia. The figure shows clearly that the American continent is dominated by bisexual populations of brine shrimps but in Eurasia there are parthenogenetic ones, although bisexual populations are common also. The separation of par-

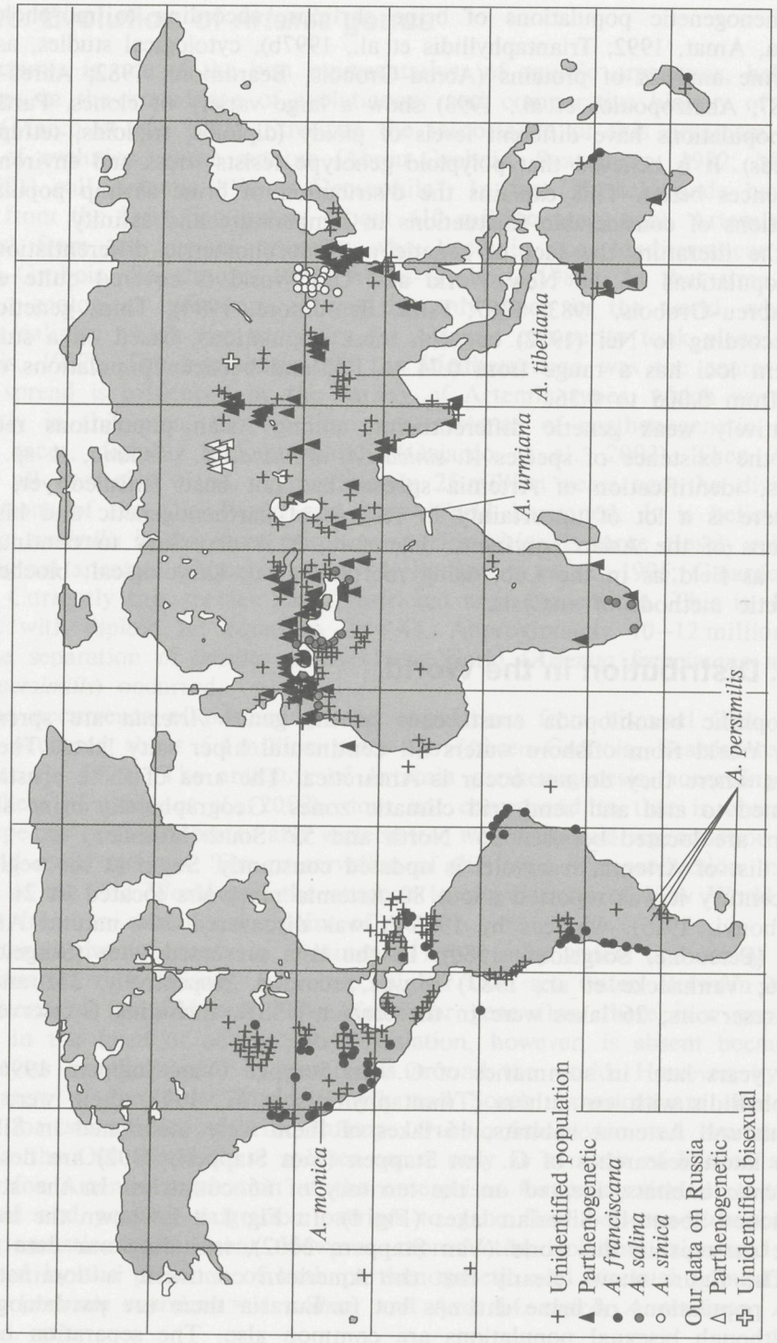

Fig. 1. Distribution of Artemia in the World (Van Stappen, 2002) with addition of our data on Russia.

thenogenetic and bisexual populations is observed also in latitudinal direction. Thus, according to some studies (Gajardo et al., 2002), parthenogenetic types of populations predominate in low and high latitudes (<25° N and >40° N), bisexual ones are in intermediate latitudes (35–40° N). In some reservoirs of Europe (Spain) there is the replacement of one type of breeding to another: in winter and spring time at low values of salinity and temperature sexual type takes place, in summer and autumn at high temperature and salinity there is parthenogenetic type (Amat, 1983).

Together with natural habitats Artemia is introduced in artificial reservoirs. Thus, in production of salt brine shrimps are used, firstly, as organisms which improve the quality of salt (due to phytoplankton consumption), and secondly, it is an additional high-value product.

1.4. Ecology and Biology

Artemia brine shrimps are primitive members of the Crustacea adapted to extreme environmental conditions (high salinity, low oxygen content, significant temperature fluctuations). In some years the reservoirs where crustaceans inhabit may be dry or frozen. In such conditions Artemia populations can exist due to high fertility and ability to sustain life beginning in winter eggs (cysts) which are in diapause and are able to maintain their viability for several years in complete drying up of reservoirs. The fact supporting the amazing Artemia vitality is associated with the discovery of living cysts (the age of them is 10 thousand years) after the drilling wells in the area of Great Salt Lake (Utah, the USA). During the incubation of those cysts live nauplii hatched (Artemia newsletter, 1987).

This Artemia extraordinarity among the animal kingdom is probably associated with the early emergence of Branhiopoda (approximately 400 million years ago). Preserved fossils (Tasch, 1963) indicate that these crustaceans have undergone only slight changes in morphological (and probably in physiological and biochemical) relations for hundreds of million years.

Brine shrimps Artemia by origin are freshwater organisms which had lived previously in continental waters. Gradually, leaving from the press of their enemies, crustaceans have adapted to life in water with high salt content. Currently, the range of salinity of Artemia habitat is wide and ranges from 10 to 340 g/l. Thus tonicity of internal circle of crustaceans remains to a constant and corresponds to tonicity size Branhiopoda from freshwater reservoirs that it proves Artemia origin. When the salinity is below 10 ‰ crustaceans carry out the hyperosmotic osmoregulation and if it is above 10 ‰ osmoregulation is hypoosmotic. A high degree of Artemia euryhalinity is caused by adaptation to existence in osmotically unstable environment which takes place in the shallow continental reservoirs. Independence of salinity in Artemia blood from salinity of environment is connected with ability of crustaceans to bring the salt which comes into the body out of an organism. The active transport of ions is carried out in specialized cells located in the gills and epithelium of intestines. In addition, Artemia brine shrimps, being in hyperosmotic environment, are sub-

jected to osmotic dehydration. To compensate the loss of water Artemia crustaceans swallow daily water in amount of 75 % by weight of the body and at the same time they reduce the urine dramatically (cit. on: Konstantinov, 1986).

It is known (Sorgeloos et al., 1986) that concentration of sodium chloride 250 g/l and above has already toxic effects on crustaceans (Fig. 2), while the salinity 70 g/l and lower is not observed for mass Artemia development, as these crustaceans do not have any anatomical protective mechanisms against predators. In addition, Artemia shrimps have a longer period of maturing (about 16 days) compared with other organisms (Rotifera, Cladocera, Copepoda), which can coexist together with consumers (Nimura, 1987). Probably for the same reason, Artemia is not competitive with peaceful zooplankton groups. Salinity at which, as a rule, Artemia develops, is the top limit both for predators and for organisms-filtrators. According to many authors (Bhargava et al., 1987; Wear, Haslett, 1987) the most favorable salinity for Artemia is in the range from 90 to 200 ‰. It should be noted that for growth and survival preferred salinity is at the bottom of this gradation (about 90–170 ‰) but for production of cysts it is in the upper part (about 120–200 ‰).

For multimillion history of their existence these organisms are unable to adapt to the possibility of nauplii hatching from cysts in conditions of high salinity, remaining, in fact, fresh-water organisms. For hatching of nauplii from cysts in the most part of studied populations required salinity is ranged from 5 to 85–90 ‰ (Lavens, Sorgeloos, 1987a, b). In some populations the threshold of salinity for hatching of cysts may be higher, for example, in Lake Ontario it is 125 ‰ and in Mono Lake — 190 ‰ (Ivanovskii et al., 1981; Dana, 1981; Thun, Starrett, 1987). Therefore, for hatching of nauplii from cysts significant dilution of brines is required, which happens when fresh water intakes with the rains, when snow and ice melt and surface water inflows from coasts and

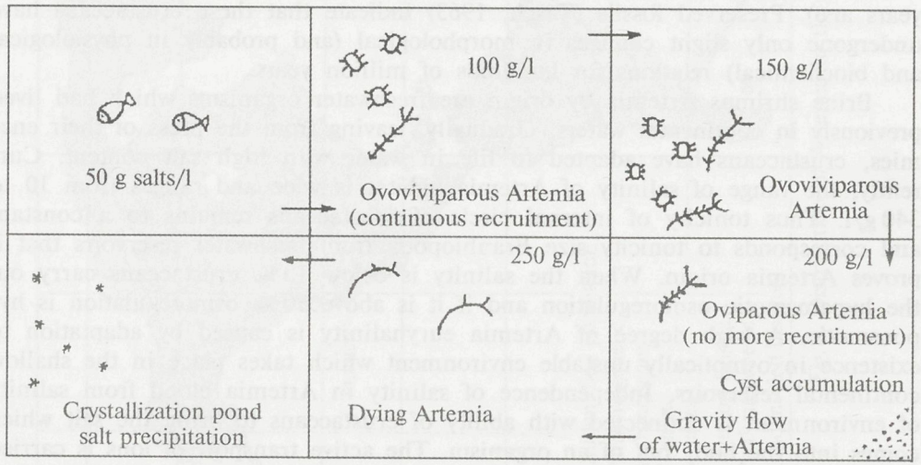

Fig. 2. Schematic diagram of solar salt operation with natural occurrence of Artemia (from Sorgeloos et al., 1986).

springs. Under the action of desalinated water cyst is hydrated, its shell is broken and alive nauplius is born. Fresh water isn't necessary now and it is even contraindicated — nauplii can die in it during next few hours.

In reservoirs with high salinity, due to their exceptional osmoregulation ability in absence of predators and food competitors Artemia brine shrimps practically develop in monoculture. Their density is controlled only by the amount of food. As in natural habitats as in artificially created and intensively managed ponds Artemia can achieve density till 100–500 ind./l and biomass 20–200 mg/l (Sorgeloos et al., 1986; Tackaert, Sorgeloos, 1991). On long-term data (Solovov, Studenikina, 1990; Evstigneev et al., 1997) values of Artemia biomass in lakes of the South of Western Siberia were in the range of 1.43–310.0 g/m^3. However, in small lake (75 hectares) located in Chelyabinsk region, with water salinity 95.4 g/l the case of record for natural reservoirs biomass (715 g/m^3) was recorded (Litvinenko et al., 2000).

Artemia's filtrational apparatus is not able to capture selectively only edible particles; Artemia is non-selective filter feeder of food (Reeve, 1963a). Therefore, crustaceans consume as living organisms (algae, bacteria) as substances of biological origin (detritus) and mineral particles. Starvation, even insignificant, can cause the death of crustaceans. Daily diet of brine shrimp is about 20 % of body weight at 28 °C, and Artemia is able to absorb this diet out of the water containing 35–350 mgC/m^3 (Nimura, 1967). At higher concentration of food in environment the value of daily diet can be increased till 160 % of body weight (Sushchenia, 1962). The degree of food assimilation reduces significantly.

Artemia is a thermophilic organism, the temperature optimum for different populations is in the range from 20 to 30 °C (Bogatova, 1980; Bhargava et al., 1987; Van Stappen, 2002), but brine shrimps can live at temperature from 2 to 35–37 °C. However, some Thai and Vietnamese Artemia populations are adapted to the temperature nearly 40 °C (Vos, Tunsutapanit, 1979; Clegg et al., 2001). According to literature data the water temperature in Artemia habitats varies in wide ranges: from –3 °C to 42 °C (Bogatova, 1980), and in shallow lakes of the Black Sea area water can warm up to 38.7–45.9 °C (Vekhov, Vekhova, 1994). At temperature below plus 5 °C movement of crustaceans is slowed down, at this temperature crustaceans do not grow (Reeve, 1963b). The seasonal occurrence of crustaceans in reservoirs depends on the climate of the area. So, in the lakes of the South of Western Siberia (Fig. 3) and Northern Kazakhstan Artemia appears, as a role, in the mid of April till at the beginning of May; in reservoirs of the Crimea and the North-Western part of the Black Sea (Voronov, 1973; Olejnikova, 1979, 1980; Vekhov, Vekhova, 1994) crustaceans develop in March — early April, in deep Alpine Mono Lake (California, USA) they are in March when the water temperature consists 2–8 °C (Thun, Starrett, 1987). In tropical and subtropical climate Artemia lives and breeds all year round (Lenz, 1987; Lenz, Dana, 1987; Wear, Haslett, 1987). The stability of nauplii to low temperatures is amazing (Baust, Lawrence, 1970). In 1–4 M solution of glycerin with the speed of freezing from 0.1 to 1.0 °C per minute individual nauplii at the age of 4 hours after hatching live up till 8 hours at the temperature –30 °C.

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Just hatched nauplii show positive phototaxis; in process of Artemia growth it changes on negative one. However, in the case of reducing the oxygen content in the water, adult crustaceans react to light positively (Waterman, 1961).

Artemia color is determined by the nature of consumed food, as well as the content of oxygen dissolved in water and varies from green to red. Artemia can withstand significant deficiency of oxygen and brine shrimps can normally

Table 1. **Limit of environmental factors determining ability to Artemia live**

Factor of environ ment	Life stage	Optimum		The boundaries of normal existence		Limits					
						survival		reproduction		metabolism	
		min	max	min	max	min	max	min	max	min	max
Salinity, ‰	Hatching of nauplii from cysts	5[A, 30, 39], 30[11]	[5–80][1], 35[A], 40[11], 50[39]							0	[32–190][1]
	Artemia shrimps: in culture	30[29], 35[5, 41], 50[14], 60[12, 13]	100[14], 170[5]	20[14]	250[29]	0[40], 0.8[44], 10[39, 53]	27[4], 280[54]	20[36]	260[5]		
	in natural conditions	90[6], 100[5, 34]	150[6, 34], 170[5], 200[34]	70[29]	250[29]		300[10], 340[8, 20]				
	Oviparity	90[38], 120[9]	130[38], 200[35]								
	Ovoviviparity	50[14], 70[38], 80[5], 120[5]	90[38], 100[14], 140[5], 200[5]								
Temperature, °C	Cysts dry	—	—								
	Cysts wet	−4[A]	+4[A]	−25[A]	25[A]	−27[23]	60[29], {90[29], 100[A, 24], 103[16], 130[39]}				
	Hatching of nauplii	23[A], 25[39]	28[39], [30][1]	−20[39]	−1[39]	−18[29]	40[29], [49][17]			4[29]	32[29]
	Artemia shrimps	20[13, 6], 25[39, 38]	27[39], 30[5], 32[38]	2[2], 4[A], [13[1], 14[39]]	33, [36–37][25]	−30[3]					
Oxygen, mg/l	Hatching of nauplii	2[29, 39]	5[36]	15	32	−3[A, 39], 2[41, 15], 6[29]	35[29], 38[18], [40[21, 22]], 42[39]	8[5], 15[4]	35		
	Artemia shrimps	2	5[36]			<0.6[47]					
pH	Hatching of nauplii	7.5[29, 49]	8.5[29, 49]	«0.3–0.5»[46], 1.5[19]		«0.17–0.29»[46]					
	Artemia shrimps			7[49]	9[49]	4[49]	10[49]				
Illumination, Lux	Hatching of nauplii	500[28]	2000[28]	6.5[36]	8[36]						
Food (diet), million cells/l	Artemia shrimps: yeast	100[50]	500[50], 1000[42], 1200[51]							20[28]	
	algae	10[41]	200[41, 52]								
Population density, Artemia shrimps/l	Hatching of nauplii from dry cysts, g/l	4[37]	5[33], 8[37]	2[37]	10[39]		17[19]				
	Artemia shrimps: in culture	5[27, 48]	10[48], 18[26]								
	in natural conditions	3[32], 10[30]	20[30], 50[31]								

Note. [1] Lavens, Sorgeloos, 1987b; [2] Thun, Starrett, 1987; [3] Baust, Lawrence, 1970; [4] Lenz, Dana, 1987; [5] Wear, Haslett, 1987; [6] Bhargara et al., 1987; [7] Scelzo, Voglar, 1980; [8] Majic, Vukadin, 1987; [9] Berthelemy-Okazaki, Hedgecock, 1987; [10] Perez Rodriguez, 1987; [11] Royan, 1979; [12] Douillet, 1987; [13] Vanhaecke et al., 1984; [14] Balasundaram, Kumaraguru, 1987; [15] Leger et al., 1983; [16] Hinton, 1968; [17] Miller, McLennan, 1988; [18] Frankenberg et al., 2000; [19] Sorgeloos, 1975; [20] Post, Youssef, 1977; [21] Vos, Tunsutapanit, 1979; [22] Clegg et al., 2001; [23] Skoultchi, Morowitz, 1964; [24] Hinton, 1954; [25] Triantaphyllides et al., 1994; [26] Tobias et al., 1980; [27] Dhont et al., 1993; [28] Vanhaecke et al., 1981; [29] Sorgeloos et al., 1986; [30] Quynh, Lam, 1987; [31] Jumalon, Robles, 1983;

exist at decrease in concentration of oxygen to 1–2 mg/l. According to K.A. Voskresenskiy and I.Sh. Haydarov (1968), the threshold concentrations of oxygen, in which there are the first signs of oppression of nauplii, juvenile and adult crustaceans, are 0.30; 0.34 and 0.50 mg/l respectively; lethal ones are 0.17; 0.22 and 0.29 mg/l respectively. In anaerobic conditions Artemia is able to stay alive at least for 2 hours (Bernaerts et al., 1985). The lower lethal limit for crustaceans is equal to 0.17 mg/l, the optimum is 6–8 mg/l (Boga-

[32] Camara, de M. Rocha, 1987; [33] Bengtson et al., 1991; [34] Tackaert, Sorgeloos, 1991; [35] Sorgeloos, 1983; [36] Lavens, Sorgeloos, 1991; [37] Coleman, 1979; [38] de Los Santos et al., 1979; [39] Bogatova, 1980; [40] Ivleva, 1969; [41] Reeve, 1963a; [42] Suschenya, 1964; [43] Gusev, 1990; [44] Chaga, 1976; [45] Nimura, 1967; [46] Voskresenskiy, Haydarov, 1968; [47] van Stappen, 1996; [48] Lavens et al., 1986; [49] Sato, 1967; [50] Coutteau, Sorgeloos, 1989; [51] Reeve, 1963b; [52] Dhont, Lavens, 1996; [53] Vekhov, Vekhova, 1994; [54] Vesnina, 2002. [ ] — parameters for different strains and species of Artemia; { } — the data at short time of exposition; « » — the data for different age stages of shrimps; [A] — own supervision.

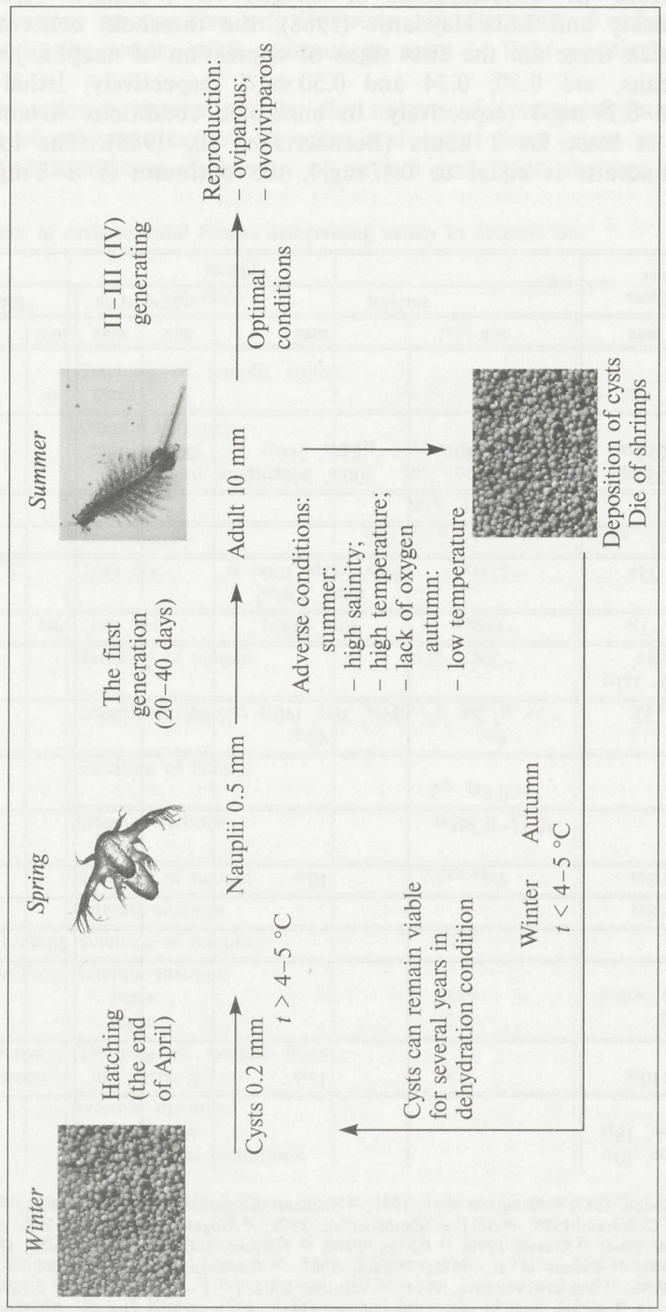

Fig. 3. Scheme of Artemia life cycle in Western Siberia salt lakes.

tova, 1980). In case of oxygen lack in the blood of crustaceans there is a strengthened hemoglobin synthesis, and their body becomes red color.

Artemia shrimps are highly resistant to contamination, in particular to high concentrations of hydrogen sulfide. It is known that hydrogen sulfide for the vast majority of aquatic organisms is dead already in small amounts. For Artemia nauplii, juvenile and adult stages lethal concentrations of hydrogen sulfide are 76, 88 and 109 mg/l respectively (Voskresenskiy, Haydarov, 1968). Perhaps, this fact explains the absence of other hydrobiont organisms in Artemia lakes which are rich with hydrogen sulfide silt.

Among all environmental factors of Artemia habitat there is a definite relationship. Simultaneously, each factor is characterized by periodic fluctuations due to climatic conditions. However, reproductive borders on the main environmental factors are more stable (Tab. 1) than for the growth process. In all cases Artemia reproduction cycles, as well as other Crustacea "are attached" in time to the periods of the best food security (Kiselev, 1980).

The limits of Artemia stability to extreme habitat conditions depend on the type of crustacean populations and their adaptability to live in the specific conditions of reservoirs. Different populations have some different indicators of survival and reproduction in specific environment conditions. In general, it can be noted that the edge values of abiotic factors of environment (oxygen, temperature, salinity, acidity, light, the amount of food, population density), which are shown in Tab. 1, are very wide and vary considerably depending on the stage of Artemia development.

1.5. Structure of Artemia body, Reproduction and Ontogeny

The shrimp body (Fig. 4) has an elongated shape and consists of three parts: the head, thorax and abdomen. On the head there is one unpaired eye, two large compound eyes sitting on the stems, antennas, antennules and mouthparts (mandibles and maxillae). The breast department consists of eleven segments, each segment carries a pair of leaf-like legs. Each leg has several outgrowths: three exopodites (function as gills) and five endopodites (involved in swimming movements and filtering out food particles). Abdomen devoids of limbs and consists of eight segments. The first two segments of abdomen are fused into one sexual segment bearing female's egg sack, and male's copulatory organ. The abdomen finishes with end-plate (furca) consisting from two branches which are feathered by setae.

Depending on the salinity Artemia shrimps form various morphological races which are differed by body sizes, the ratio of abdomen length and width, structure of furca. As a rule, with increasing of salinity the relative length of abdomen increases and abdomen width decreases. At the same time there is a reduction of furca and reducing the number of bristles on it (Fig. 5).

Artemia shrimps are dioecious. Males are distinguished by the presence of pair of hooked grabbers located in the head. Artemia females are easily recognized by egg sack. There are both bisexual and parthenogenetic races. In Ur-

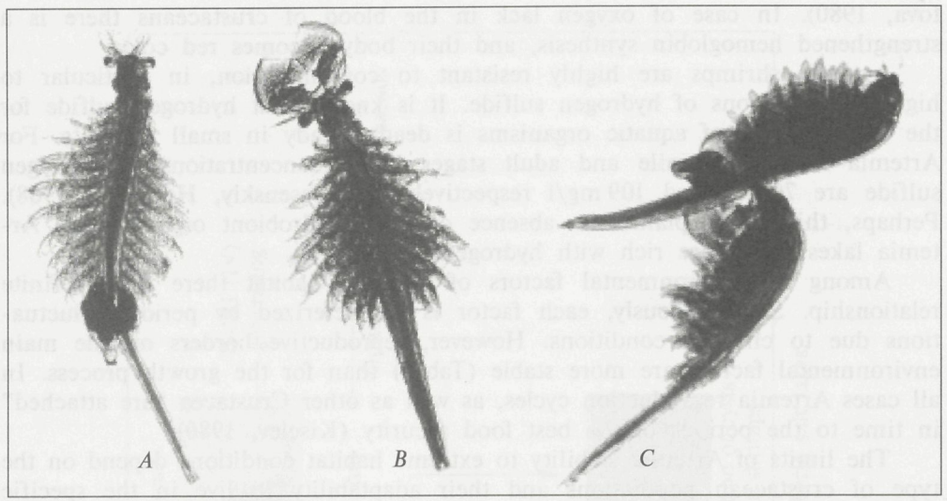

Fig. 4. Artemia shrimp.
A — female; *B* — male; *C* — pairing (photo from the archive Artemia Reference Center, Gent, Belgium).

mia Lake (Iran) parthenogenetic race coexists with the bisexual species *Artemia urmiana* (Takami, 1989). It is possible to change one type of reproduction to another. For example, sexual type of reproduction observed in spring and winter changes in parthenogenetic type which occurs in other seasons (Amat, 1983). The change of parthenogenetic race on dioecious one happens when it takes place the transferring cysts in aquariums (Chaga, 1976) and also when there is a chang of feeding conditions: parthenogenetic race is after feeding by microalgae and dioecious one is after feeding with mixed feed.

Artemia shrimps multiply nauplii and two types of eggs with thin and thick shells (cysts). From the first eggs hatching of nauplii occurs immediately after spawning or after 2–5 days (Wear, Haslett, 1987), from the second ones — after emerging them from diapause. Nauplii have undifferentiated body painted in orange color, which is determined by the content of carotenoids in hypodermis. The sizes of nauplii depend on the sizes of eggs (the body length — is 0.4–0.6 mm; weight is from 0.01 to 0.06 mg). In initial stages of development nauplii grow rapidly at the expense of yolk reserves. Nauplii of the first larval stage (Instar I) (Fig. 6*A*) can not consume food; their digestive system does not function because mouth and anus are still closed. In 8–12 hours after the first molt nauplial period finishes and *Artemia*

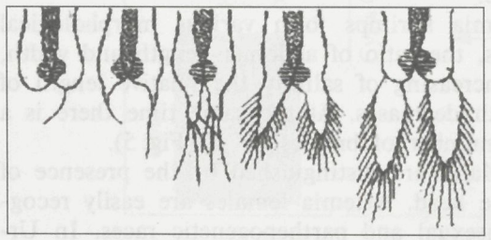

Fig. 5. Change of Artemia furca at different salinity (on Wagler, 1925).

larvae enters metanauplial stage. The digestive tract of larvae I metanauplial stage (see Fig. 6*B*) starts functioning and there is a possibility to filter the particles of size 1–40 μm. Over the next 8–10 days crustaceans pass the following three metanauplial stages characterized by different degree of segmentation of the body. After the fifth molt metanauplial period finishes and juvenile period with the 7th stages of development (see Fig. 6*C*) begins. It is followed by conversion of antennas and development of thoracopods (thoracic legs). After the thirteenth molt preadult period consisting of 5 stages of development begins (see Fig. 6*D*). This period is characterized by the development of Artemia genital structures: the second pair of antennas undergoes sexual differentiation. Hooked grabbers are developed at males, while females have antenna reduced in sensory appendages (see Fig. 2). When the length of shrimp is 6 mm or more it is already possible to discern the future males and females. After the seventeenth molt the post-embryonic development is completed; crustaceans have all sexual characteristics. The stages of Artemia development in details are covered in literature (Criel, 1991; Litvinenko et al., 2000).

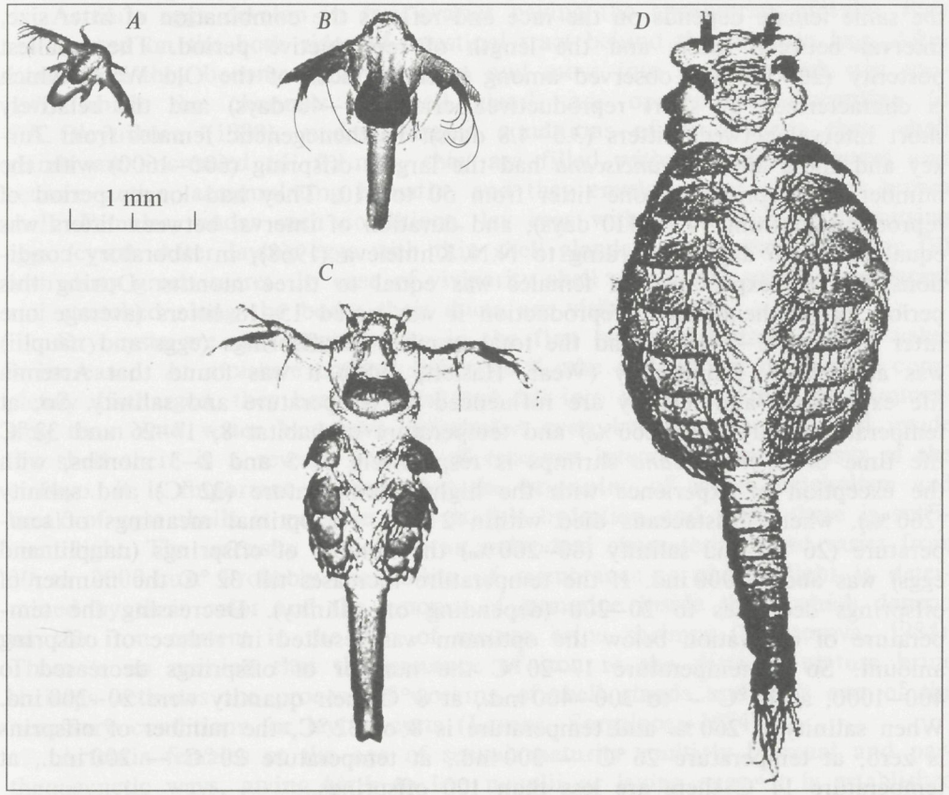

Fig. 6. Stages of Artemia development (on Schrehardt, 1987).
A — nauplius; *B* — metanauplius; *C* — juvenile; *D* — pre-adult.

Crustaceans become mature sexually at the age of 20–35 days whith the body length 8.5–9.5 mm, after that their growth is slower (Ivleva, 1969). Under optimal conditions (in culture conditions) maturation occurs for 8–16 days (Sorgeloos et al., 1986), and the first matured females (*A. franciscana*) have the length about 6 mm (Wear, Haslett, 1987). Some old individuals can reach 15–18 mm long and 6–8 mg of biomass. Females of some parthenogenetic populations reached 19–20 mm long (Sorgeloos et al., 1986; Lenz, Browne, 1991), which is probably explained by the phenomenon of polyploidy. In bisexual populations crustaceans after reaching maturity begin to form pairs. With help of antennas males capture genital segment between anterior end of the egg sack and the last couple of thoracopods. According to observations of N.V. Vekhov and T.P. Vekhova (1993) hitches can consist of as females and males as females and several males.

During the cultivation in optimal conditions, on average, one individual can lay 100–300 eggs (or nauplii) with an interval from 4 till 11 days (Sorgeloos et al., 1986). In laboratory experiments with different *Artemia* races it was established (Browne et al., 1984) that the total number of offsprings produced by the same female depends on the race and reflects the combination of litter size, interval between litters and the length of reproductive period. The smallest posterity (20–30) was observed among bisexual races of the Old World which is characterized by short reproductive period (20–40 days) and the relatively short interval between litters (3.5–4.8 days). Parthenogenetic females from Turkey and India and *A. franciscana* had the largest offspring (600–1600) with the number of offsprings in one litter from 50 to 110. They had longer period of reproduction (from 40 to 110 days), and duration of interval between litters was equal to 4.6–6 days. According to N.N. Khmeleva (1968), in laboratory conditions the life expectancy of females was equal to three months. During this period for parthenogenetic reproduction it was noted 15–18 litters (average one litter in every 5–7 days), and the total number of offsprings (eggs and nauplii) was about 900. Empirically (Wear, Haslett, 1987) it was found that Artemia life expectancy and fertility are influenced by temperature and salinity. So, at temperate salinity (140–260 ‰) and temperature of habitat 8, 17–26 and 32 °C life time of *A. franciscana* shrimps is respectively 6, 5 and 2–3 months, with the exception of experience with the highest temperature (32 °C) and salinity (260 ‰), where crustaceans died within 2 days. At optimal meanings of temperature (26 °C) and salinity (80–200 ‰) the number of offsprings (nauplii and eggs) was about 1000 ind. If the temperature increases till 32 °C the number of offsprings decreases to 20–200 (depending on salinity). Decreasing the temperature of cultivation below the optimum was resulted in reduce of offspring amount. So at temperature 17–20 °C the number of offsprings decreased to 400–1000, at 14 °C — to 300–400 ind., at 8 °C their quantity were 20–200 ind. When salinity is 260 ‰ and temperature is 8 or 32 °C, the number of offsprins is zero, at temperature 26 °C — 300 ind., at temperature 20 °C — 200 ind., at temperature 14 °C there are less than 100 offsprings.

In natural reservoirs Artemia fertility depends on many factors. In tropical and subtropical conditions with year-round Artemia growing season the fecundity of crustaceans is small: there are 1–4 nauplii in Laysan Lagoon Lake, Hawaii (Lenz, Dana, 1987); 5–6 ind. in Boca Chica Lake, Venezuela (Scelzo, Voglar, 1980). In temperate latitudes with intermittent winter vegetation of crustaceans the fecundity is relatively high: up to 130 cysts (rarely nauplii) at high phytoplankton biomass in June in Mono Lake, California, USA (Lenz, 1982), 66 eggs per litter in Bulgarian salt lake (Ludskanova, 1974). In Great Salt Lake there are 30–50 cysts at viviparity and less than 20 cysts if females have cysts in ovisacks (Lenz, Dana, 1987). The average sizes of litter for different Artemia populations are in the range from 21 to 111 eggs/litter (Browne et al., 1984).

Thus, both Artemia ontogenesis and its fertility are determined by environmental conditions. Less productive communities are typical for reservoirs with relatively constant environmental conditions. In more productive reservoirs there are communities experiencing annual collapse (stress) resulting in high products of cysts as protective reaction of organism from extinction.

1.6. Features of Artemia Reproduction

Artemia eggs develop in two ovaries having the appearance of tube, they are located on the both sides of intestinal tract behind the thoracic legs. After maturation they become spherical form and move into a single sack (the uterus), which the channels of shell glands are opened in. According to F.A. Oleynikova (1980), under extreme conditions of crustaceans their shell glands are increased till 0.1 mm, they are filled with dark-brown secret and become active, accumulating hematin, and they envelop eggs with thick brown shell. Females, under such conditions, lay eggs with thick shell or diapausing eggs (cysts). After laying eggs with thin shell glands also increase but they fill with dirty green secret. In case of viviparity shell glands are small, transparent and stretched along the body; their ducts are visible poorly.

Dry cysts are very hygroscopic; in the first hours of hydration their value is increased. At moisture content below 10 %, the metabolism of cysts is completely discharged, they become inert and fall into diapause. Only after immersing them into water biconcave dehydrated cysts become spherical and inside the shell there is a reverse process of recovery interrupted metabolism of the embryo. It is important to note that the beginning of active metabolism and break of cyst shells is possible only at full hydration and when there is sufficient light. The intensity of light is an individual characteristic and varies from 20 to 2000 Lux. Probably the ability of membranes to absorb light is determined by their color and the amount of hematine inside them which depend on the iron content in the diet of mature brine shrimps (Spectorova, 1984). There is an opinion that the presence of iron in the diets of mature brine shrimps activates the process of working of shell glands and it is one of the necessary conditions for laying cysts (Lavens, Sorgeloos, 1984).

Artemia females at the age of sexual maturity multiply bisexual and parthenogenetic ways, giving birth to live nauplii or laying eggs. It is established that under natural conditions the processes of viviparity or ovoviviparity depend on different combinations of environmental factors, the main factors are sali-

nity, temperature, content of oxygen and conditions of supply. As it was shown earlier, shell glands of parthenogenetic females are the most sensitive to changes of these environmental factors.

Consensus about changing of Artemia reproduction methods has not existed yet. More often in summer brine shrimps produce living nauplii when there is relatively stable salinity of salt-water and in autumn they produce cysts. According to F.A. Oleynikova (1980) Artemia females lay biologically different eggs: summer and winter diapausing eggs with thick shells, summer eggs with thin shells. At the same time the author notes that at the study of microscopic sections of summer and winter eggs with thick shells there weren't any differences in their morphological structure.

P.M. Voronov (1971), watching Artemia reproduction features in glass vessels, said that it was quite difficult to distinguish in ovisac eggs with thick and thin shells. After spawning time all of them had a ball shape and their shells became sticky immediately. Eggs floated or glued to the wall of the vessel. Their color changed gradually from gray to silver or from light brown to dark brown. At the same time the structure of the shell changed; on one side of shell recess (meniscus) is formed. The eggs dehydrated gradually, lost their stickiness and sank to the bottom. The color of eggs with thin shell almost did not change, the indentation in the shell was not formed. According to P.M. Voronov, hatching of nauplii from eggs with thin shell happens during the day but some of these eggs do not develop. Females spawn such eggs in the last turn. The shell of eggs becomes fade till transparency and cracks. The content of broken egg swells, comes out in the form of formless flocculent mass and dissolves.

At high salinity indentations in eggs appeared already in ovisaks, the stickiness of these eggs was significantly weaker, more often they sank immediately on the bottom.

In autumn, when the temperature of water decreases, females produce eggs which are very different from eggs in summer; they are covered with a thick shell, which consists about third part of the egg weight. Under the protection of such shells Artemia embryos are able to endure adverse life conditions, complete drying of reservoirs, significant heating and cooling nearly to absolute zero, the action of many chemical agents which are lethal for all age groups of crustaceans. In condition of diapaused eggs at the stage of gastrula, Artemia populations can persist for several years, they are transported easily by wind, waterfowl and occur suddenly in the new lakes which have favorable conditions.

F.A. Oleynikova (1980) distinguished three types of Artemia cysts diapause:

— annual and long-term diapause, which occurs in spring and summer months and continues for a year or few years; it manifests in parthenogenetic populations with a short period of life, giving only one generation which is a rapidly dry in summer lakes. Biological orientation of diapause is the conservation of this species under bad environmental conditions;

— winter diapauses begins in August — September and lasts until spring time next year; it occurs with eggs which were layed by females from deferred bisexual and parthenogenetic races while the eggs are in salt water or in the bank of reservoirs. The biological focus of this type of diapause is a serviving the number of shrimps in reservoirs of their permanent habitat;

— summer diapause is the shortest-term (2–5 weeks), it is observed while females lay eggs with thin shells. Biological orientation is preserving Artemia amount in permanent water reservoirs with rapidly changing short term environmental conditions (temperature, oxygen content, natural food saply). In such conditions the preservation of population in the form of nauplii is temporarily impossible.

Later P. Lavens and P. Sorgeloos in their publications (Lavens, Sorgeloos, 1987a) suggested to use following terminology for the various stages of cyst development:

— **cryptobiosis** is a state of organism where there are no visible signs of life, metabolic activity becomes difficult to be determined, at the end the reversible metabolism is interrupted;

— **dormancy** (hibernation, rest) is a specific form of cryptobiosis with the endogenous control of metabolism and development (gastrula falls into this state inside the uterus of crustacean regardless of habitat);

— **quiescence** (immobility) is a condition where there is a slowdown of development, habitat controls of metabolism and development, for example, extreme temperature, oxygen, salinity, drying. Further embryogenesis is possible when conditions will be acceptable. There are types depending on the factor: **anhidrosis** (lack of moisture), **anoksibiois** (lack of oxygen), **criobiosis** (low temperature).

In the list it can be added non-dormant eggs which hatch immediately after laying.

There are several hypotheses explaining the mechanism of diapause. One of them is based on the regulation of permeability of cyst membranes, depending on their thickness, density, microstructure, chemical composition (Anderson et al., 1970). Another hypothesis is based on the fact that splitting of carotenoproteins as free carotenoids as proteins diapause is terminated and cysts from the state "dormancy" are transferred to the stage "quiescence" (Dutrieu, 1960). And, finally, the third hypothesis (Crowe et al., 1987) is based on changes in internal pH of cyst medium, in which the state of "dormancy" can be induced by internal pH which is higher than physiological norm ($pH_i > 7.9$).

1.7. The Reasons for Cyst formation

Practical use of Artemia in aquaculture is mainly attributed to the ability of crustaceans to form cysts, which remain viable for a long time and at any time it can be used for mass start of receiving live food in the form of nauplii or decapsulated cysts.

The largest supplies of Artemia cysts were registered in the United States, where only in Great Salt Lake (State Utah) since the eighties of the XX century annually from 3 to 10 thousand tons were harvested. In small quantities

cysts are harvested in Canada, Thailand, Vietnam and several other countries. There are large Artemia stocks in Turkmenistan, Kazakhstan, China. In reservoirs of Russia under favorable climatic conditions it is possible to catch 1.5–2.0 thousand tons annually.

The cause of cysts appearance is probably the deterioration of environmental conditions. The proof of this opinion is the fact that in stable favorable conditions cysts are formed barely and zoogony dominates (Lenz, Dana, 1987).

In Fig. 2 the distribution of Artemia in waters with different salinity is presented graphically. In Fig. 3 Artemia life cycle in the lakes of Western Siberia is shown, as well as the reasons of cyst formation are noted.

From many factors contributing to cyst formation it is possible to highlight the most important:

— increasing the salinity of water above 150 g/l (Sorgeloos et al., 1986);

— falling content of oxygen below lethal limit (Sorgeloos et al., 1986; Litvinenko, Matveeva, 2001);

— decreasing and increasig water temperature up to values closed to the limits of species survival (Sorgeloos et al., 1986; Litvinenko, Matveeva, 2001);

— the reduction of day length at a temperature below 25 °C (Berthelemy-Okazaki, Hedgecock, 1987);

— deterioration of trophic conditions (Tsareva, 2004).

According to some studies (Dutrieu, 1960) the presence of algae in the diet of crustaceans is necessary condition for cyst appearance.

1.8. Morphology and Metabolism of Artemia cysts

Taking into account the special significance of cysts, let us consider their structure more (Fig. 7). Cyst shell consists of three distinct layers: chorion, outer cuticular membrane and embryonic cuticle (Sorgeloos et al., 1986). Outer shell (chorion) is a solid layer impregnated with chitin and hematine; the concentration of chorion determines the color of the shell (from pale to dark brown). The main function of chorion is the protection of embryo against mechanical damage and UV radiation. This layer can be removed with help of decapsulation, while the viability of embryo is stored. The second alveolar layer (cuticle membrane) is quite thick (up to 6–7 microns), inside this layer there are two caveties connected to each other. This layer of the shell protects the embryo against the penetration of large molecules, acts as a semi-permeable barrier and plays a major role in hydration or dehydration of cysts. The bottom layer (embryonic cuticle) develops during incubation; it is transparent and highly elastic layer separating the embryo from cuticular membrane.

The average diameter of cysts from different populations is in the range from 0.22 to 0.29 mm (0.33 mm — *A. tibetiana*), the mass of wet cysts is 0.006–0.015 mg, dry cysts — 0.0028–0.0075 mg, the weight of the shell is approximately 30 % of cyst weight (Dutrieu, 1960; Bogatova, 1980; Sorgeloos et al., 1986; Abotzopoulos et al., 1998).

The embryo of diapausing egg (cyst) is undifferentiated stage of gastrula and has no metabolism completely at moisture content below 10 %. When the

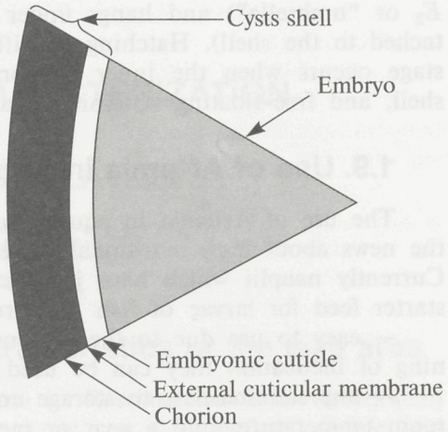

Fig. 7. Schematical diagram of ultrastructure of Artemia cyst.

humidity is above 10 % and there is an oxygen (e.g., it presents in the air), viability returns to embryo.

Dry cysts (humidity 2–5 %) are very resistant; the quality of their hatching does not reduce when they are stored in temperature range from –273 to 60 °C. At temperature from 60 to 90 °C dry cysts are stable only at brief exposure (Sorgeloos et al., 1986). In experiment cysts withstand intermittent temperatures up to 130 °C (Bogatova, 1980).

Hydrated cysts have a very specific temperature tolerance (Sorgeloos et al., 1986):

— at temperature below –18 °C and higher 40 °C irreversible stop of metabolism (destruction of embryos) takes place;

— at temperature between –18 to 4 °C and between 32 and 40 °C reversible stop of metabolism takes place;

— at temperature from 4 to 32 °C an active metabolism takes place. The hatching will be faster at higher temperatures, but the percentage of hatching remains constant.

Humidity of hydrated cysts in commercial catches, to our knowledge, is in the range from 50 to 65 %.

Amazing viability was observed in cysts with humidity 36 % or less. According to E.E. Gusev (1982), single cysts remained their viability at heating to temperature 140 °C during 24 hours. Our experiments connected with temperature tolerance of dry and hydrated cysts from Artemia Siberian populations showed follow mechanism. After exposure of dry cysts in water with temperature about 100 °C within 2–5 minutes the percentage of nauplii hatching decreased from the original 70.5 to 3–5 %, hydrated cysts within 2 minutes reduced from 78.5 to 3.6 %. Longer exposure time resulted to complete destruction of cysts.

Dry cysts are very hygroscopic and absorb water, i.e., in the early hours volume and weight of hydrated cysts increase more than 100 %. The beginning of active metabolism is possible only after cyst full hydration (140 % of water), when there is sufficient light and presence of oxygen.

In App. 1 the scheme of Artemia cyst development during incubation until nauplii hatch is shown. Hydrated cysts do not change their diameters. Dry cysts having a biconcave shape, acquire spherical shape after 1–2 hours placing them in the water. After 15–20 hours of hydration cyst shell ruptures (stage "break" or the first embryonic stage E_1), and prenauplius surrounded by the inner membrane becomes visible. The embryo leaves the shell completely (stage

E_2 or "umbrella") and hangs under empty shell (inner membrane is still attached to the shell). Hatching or differentiation prenauplius to the 1st nauplial stage occurs when the inner membrane separates completely from the empty shell, and free-floating Artemia larvae appears.

1.9. Use of Artemia in Aquaculture

The use of Artemia in aquaculture began in the 40-s of XX century after the news about high nutritional value of nauplii (Seale, 1933; Rollefsen, 1939). Currently nauplii which have just hatched are considered one of the best live starter feed for larvae of fish and crustaceans. It is connected with:

— easy to use due to the presence of cysts (the next day from the beginning of incubation they can be used as live feeds);

— unpretentiousness to storage conditions of dried cysts (they are stored at room temperature until a year or more);

— high content of proteins, highly unsaturated fatty acids (HUFA), essential amino acids, some vitamins (A, B, C, thiamin, niacin, riboflavin and others), hormones;

— small sizes of nauplii and soft thin outer skeleton.

In addition to nauplii decapsulated cysts are used in aquaculture for feeding fish larvae. Reared Artemia shrimps are used for feeding fish fries. Last decade the method of improving nutritional qualities of nauplii and crustaceans by their enrichment with help of various food supplements: essential nutrients, pigments, preventive and therapeutic preparations is spread worldwide.

Currently in Western Siberia there are several enterprises on processing of cysts in prepared products with total production more than 1.0 thousands tons per year.

Chapter 2

BIOGEOGRAPHY AND CHARACTERIZATION OF NATURAL HABITATS OF SIBERIAN ARTEMIA POPULATIONS

2.1. General geographical characteristics of the lake area

The area of Artemia in Western Siberia in Russian Federation is between 51–56° North latitude and 61–82° East longitude and it is confined to the arid steppe and partly forest-steppe. From the West the area is limited to the Eastern slopes of the Ural mountains, from the East — West slopes of the Altai mountains and Salair ridge, from the North — line Barabinsk — Tyukalinsk — Ishim — Shadrinsk — Chelyabinsk, in the South it is adjacent to the Kazakhstan area of semi-desert zone (Fig. 8, see inset). All this vast territory located in the southern part of the Ob-Irtysh basin, includes the following administrative regions: Chelyabinsk, Kurgan, Tyumen, Omsk, Novosibirsk and Altai region. On the Eastern border of this area in the foothills of the Western Sayan mountains in Khakasia and Tuva there are several reservoirs with Artemia (App. 2).

2.1.1. Relief

The relief of area is presented by sloping plains, folded with lacustrine-alluvial and deluvial sediments of sand, loess-like loams and clays of the Neogene and Quaternary (Dzens-Litovskiy, 1968). The river sistem is fairly rare. It is characterized by a large number of inland lakes, part of which is located below the level of the river Irtysh. A characteristic feature of the landscape is the presence of hills (ridges), alternating with hollows. The absolute height of interfluvial spaces reaches 100–140 m, in Kulunda plain — 160–200 m, in the Priobskoye plateau — 200–300 m (Agroclimatic resources..., 1971, 1972).

2.1.2. Climate

The study area occupies six distinct natural complexes, they are elongated meridionally and arranged in parallel to each other:

— Pre-Ural plateau to river Tobol (13 Artemia lakes);

— the area between rivers Tobol and Ishim (18 lakes);

— the area between Ishim and Irtysh (1 lake);

— Barabinsk — Kulunda depression (45 lakes);

— the Priobskoye plateau (2 Artemia lakes);

— the area between rivers Ob and Yenisei — the region of Western Sayany (4 lakes).

Each of these zones has the traits of individual landscape and it is characterized by certain weather complex. For example, differences in mid-January temperatures of these zones reach 4 °C, differences in mid-July temperature are less (0.6 °C), differences in average annual temperature are 2.4 °C (App. 3).

In general this area has so-called South-Siberian weather complex which, according to A.P. Slyadnev (1965), is characterized by the following indicators:

— radiation balance — 36–45 kcal/cm^2 per year;
— evaporation is about 600 mm per year;
— the quantity of rainfall — 250–400 mm per year;
— the annual deficit of precipitation is from 100 to 300 mm;
— the sum of temperatures above 10 °C is 1900–2400;
— hydrothermal coefficient is from 0.6 to 1.2;
— the number of days with snow cover is 155–170;
— date of formation of stable snow cover — 1–11 November;
— date of tails of snow-cover is 16–21 April;
— summer time (temperatures above 15 °C) is from 3–5 June till 27–30 August.

In general, according to agro-climatic zoning, the climate of the region is continental or sharply continental, warm or hot, with insufficient moisture or dry.

In general, the climate is characterized by short and warm or hot summer, long cold winter. Unhindered penetration of cold Arctic air mass from the North and dry mass of Kazakhstan and Central Asia leads to climate instability. The average annual precipitation in forest-steppe zone does not exceed 350–400 mm. In steppe zone precipitation is even less, it is about 300 mm per year. The most part of precipitation falls in warm season of the year. Their number is increased considerably since May and reaches maximum in July; minimum of precipitation is in the second half of winter and beginning of spring. Evaporation occurs mainly in warm season and exceeds rainfall during this period in 1.5–2 times. Total evaporation in the North forest-steppe zone is 350 mm, decreasing to the South up to 300 mm due to decrease in precipitation. In steppe zone at high evaporation actual evaporation, limited precipitation and soil moisture, is reduced to 300–250 mm, making 98–99 % of gross soil moisture (Agroclimatic resources of the Altai Krai, 1971; Agroclimatic resources of Omsk region, 1971; Agroclimatic resources of Novosibirsk region, 1971; Agroclimatic resources of Tyumen region, 1972; Agroclimatic resources of Chelyabinsk region, 1977).

2.1.3. Soils and vegetation

Soils are represented by leached black soils, salt marshes and saline lands. Salt marshes sometimes occupy large areas, especially in flat valleys and lake depressions. The vegetation is characterized by the alternation of birch and aspen and grass-forb steppe areas, now the most part of them is under cultivation. In saline soils vegetation cover is poor and mainly consists of grass,

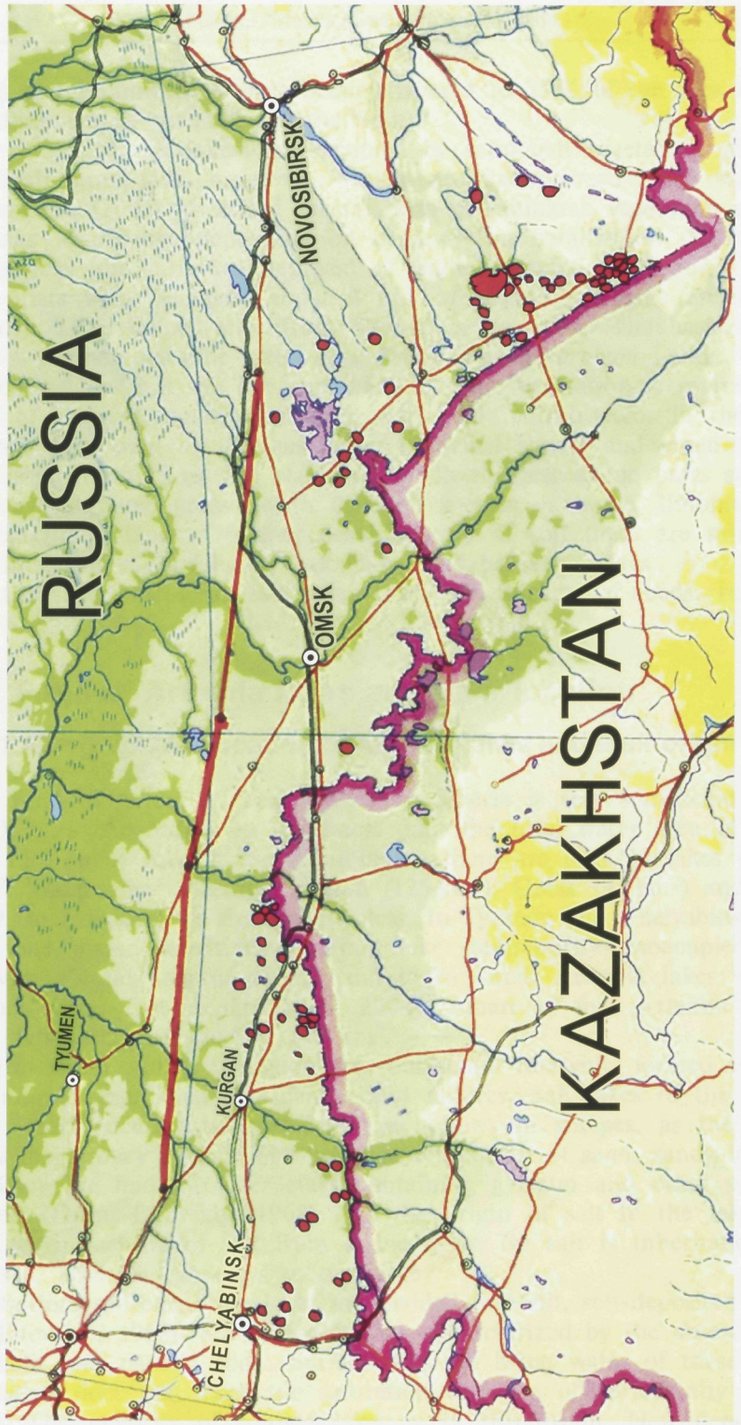

Fig. 8. The Siberian area of Artemia distribution within Russia.
Artemia Lakes are designated red, their northern border is designated red line.

sagebrush and limonium. Forests occupy from 4 to 25 % of the area of forest-steppes disappearing gradually to the South.

The shores of salt lakes are occupied by saltmarsh vegetation, alternating above alkali grass-forb meadows, which are interspersed with woodlands. N.I. Naumenko (2001) identified several belts of saltmarsh vegetation on investigated lake Medvezhye depending on degree of mineralization. So, the most saline parts of the lake are deprived of higher vegetation. Ground sediment bacterial mats with thickness about 4 mm are bared on brine areas flooded periodically. Their color varies from olive-green to black. The basis of bacterial mat is filamentous blue-green alga *Phormidium dimorphum* Lehm., *Ph. jadinianum* Gom., *Lyngbya* sp. The first band of high vegetation is represented by a carpet of saltwort, which has small sizes and reddish color in the area of the oppressed growth; also it has larger branched shoots and green color depending on distance from the water edge. On the less saline parts saltwort is replaced by saltmarsh grasses with different species of swede, limonium, halimione, bascillica. Due to further desalinization of soil there are saline associations including 60 species of halophytes and haloxenophytes.

On the shores of some salt lakes there are thickets of reeds, rushes and cattails.

2.2. Fund of Artemia lakes and their location

2.2.1. Geographical location of Artemia lakes and their origin

The fund of Artemia lakes in Western Siberia is very significant and has about 80 lakes. According to the latest data the total water area of Artemia lakes is 1567 km^2. Only in the Altai region there are over 30 lakes with area 1180 km^2. Water area of Kurgan region (125 km^2), Omsk (92 km^2) and Novosibirsk (99 km^2) regions are significantly less. In Tyumen and Chelyabinsk regions there is one major potentially Artemia lake (temporarily unoccupied by Artemia) with a total area of 65 km^2 and a few small Artemia lakes with total area about 5 km^2 (Litvinenko et al., 2004). Square of four Artemia lakes located in Khakasia and Tuva is 14.4 km^2.

Origin Artemia lakes in region are continental reservoirs formed as a result of erosion, blowing, karst subsidences and failures. Salt lakes of the South of Western Siberia occupy internal-drainage hollows in siltages, as the latest of origin as the tertiary period. The upper layers consist of sand, sandy loams and loams. They are laid by older clays containing gypsum and other salts. It is considered (Dzens-Litovskiy, 1968) that the origin of salt in the lakes is associated with leaching of salt from saline clays. So salt is inheritance of the tertiary sea, preserved in clays to our time.

On bottom sediments the lakes are divided into silt, self-deposited and root (Dzens-Litovskiy, 1968). Silt sediments are characterized by the absence of mirabilit, halit and natural soda. Surface and silt brine water of these lakes in concentration does not reach the saturation any one of periodically deposited minerals. The majority of studied lakes is in this group. New deposition of

periodically deposited mineral takes place in self-deposited lakes. The mineral appears and re-dissolves during one annual cycle (e.g., lake Ebeyty). In addition to new deposition root lakes have sediments of old deposition and root salts (for example, the lakes Kuchukskoye and Tanatar, which have root reservoir of mirabilit respectively and natural soda).

2.2.2. Morphometric features and hydrological regime of the lakes

The water area of salt lakes ranges from several to tens of thousand hectares. The banks are low, marshy in some places; litoral is sand but with muddy sediments. In ultra saline lakes in the presence of Artemia crustaceans mud deposits reach large capacity and they are represented in the form of viscous mud with deep black color and smell of hydrogen sulfide. Such deposits are typically used in balneological purposes (for example, Medvezhye lake).

There are 20 large lakes (>10 km^2), 47 medium lakes (1–10 km^2). All other reservoirs are small with area less than 1 km^2. It can be attributed 1 lake to relatively deep (>4 m) reservoir. There are 6 lakes with average depth 2.0–3.5 m; all other lakes are shallow with depth less than 2 m.

Morphometric indicators of main Artemia lakes and their geographic coordinates are given in App. 2.

Artemia lakes on the type of water recirculation, as a rule, are closed. As precipitation as surface and underground drain waters play the main role in nutrition of continental salt lakes. According to A.I. Dzens-Litovskiy (1968) mineralization of groundwater in steppes of Western Siberia can reach 40–50 g/l, in soil solutions it is 300–400 g/l. Precipitation can give per year: NaCl — 10.5; Na_2SO_4 — 8.5; KCl — 10.5; K_2SO_4 — 8.0; $MgCl_2$ — 2.5; $CaSO_4$ — 6.5; $CaCl_2$ — 2.0; $MgSO_4$ — 6.0 kg/ha. Ratio of elements in brine of salt lakes depends on the concentration of salt, the composition of rocks of the lake basin, the character of the bottom silts, climatic factors and others.

The number of Artemia lakes in the region and their water area depend on conditions of water availability and can fluctuate significantly in some years.

The water level of plain Siberian lakes undergoes periodically strong oscillations until complete drying of small lakes and significant reduction in sizes and depths of large ones. If water level falls down fresh water lakes are brackish, brackish lakes are salt. When the water level rises reverse processes take place. Hydrological regime of small lakes which can be a place of temporary Artemia living is the most unstable. In such lakes Artemia crustaceans in some years die due to decreasing of water salinity and populations are stored in the form of cysts.

2.2.3. Types of lake basins

On morphometry of lake basins and nature of water supply lakes in the region are divided into four types (Litvinenko et al., 2004):

— reservoirs with flat and rounded depressions, with high steep banks, sandy soils in littoral. The ratio of lake area to catchwater area ranges from 0.05 to 0.10; recharge is occured primarily by underground or coast ground waters, often feeding of the lakes is complemented by bottom waters (for example, lake Bolshoye Yarovoye);

— reservoirs with the basin of irregular shape, with low banks. The maximum depths do not exceed from 2.0 to 2.5 m, the average depth is about 1.0 m. Coast line is rugged and swampy in some places. The ratio of lake area to water catchment area increases to 0.30; water supply is due to underground water and, more often, surface runoff water (the most lakes of the region);

— reservoirs are fed by surface runoff water and dry up in some years in the middle of summer. The average depth of these lakes is about 0.5 m. In these high saline lakes usually there are conditions (often quite favorable) for formation of only one or two generations of crustacean (e.g., the lakes Ebeyty and Petukhovskoye);

— reservoirs with a very shallow basin, feeding by surface runoff water, periodically drying up in years with lower water content. The average depth is less than 0.4 m. In such lakes Artemia population finishes its activity for a number of years and continues to exist in the form of cysts buried in the bottom ground.

2.3. Physico-chemical characteristics of the lakes

2.3.1. Hydrochemical characteristics of the lakes

2.3.1.1. Average seasonal indicators of hydrochemistry of the lakes

Artemia lakes of the region on the amount of ions belong to hyper-saline reservoirs. The total mineralization of water in Artemia lakes in summer and autumn during the studies ranged from 28 to 371 g/l (App. 4). Extreme levels of salinity where crustaceans were dwelled are from 34 g/l (Setovo) till 299 g/l (Ebeyty) and according to Z.I. Novoselova and V.A. Novoselov (2000), even 320 g/l in Kuchukskoye lake. In the lakes Siverga and Tauzatkul Artemia were absent at mineralization 28–30 g/l, in the lake Ebeyty — at salinity 371 g/l. All studied lakes are brine lakes, Ebeyty in dry years is self-deposited lake. Water in the lakes is clean, transparent, sometimes yellow-green (the lake Gashkovo) with varying degree of opalescence or milk color (lake Kulundinskoye). Opalescence of water caused by the presence of suspended salt micelles was decreased in some lakes (Maloye and Bolshoye Medvezhye) from spring to summer.

On the composition of ions brines of Artemia lakes are divided into three classes:

— chloride (salts NaCl, $MgCl_2$, $CaCl_2$ dominate);

— sulfate (with high content of sulfate salts Na^+ and Mg^{2+});

— carbonate (soda with relatively high concentration of HCO_3^- and CO_3^{2-}).

Brines of the most Artemia lakes apply to the first class including the largest lakes in the region: Bolshoye Yarovoye, Kulundinskoye, Medvezhye.

Sulphate lakes are about 10 % of all Artemia lakes. Ebeyty, Kurtamyshskoye and three lakes from Khakasia (Tus, Cheder, Pervomayskoye) belong to

typical sulfate lakes. These lakes are differed by significant content of easily soluble salts in water, which crystallize upon cooling the brine in autumn-winter period and precipitate during evaporation of water in summer.

Carbonate Artemia lakes among the studied reservoirs are not found. In the Altai region according to V.P. Solovov and T.L. Studenikina (1990) the lakes Tanatar and Petukhovo belong to this group of lakes.

According to O.A. Alekin's classification with co-workers (1973), water of the most studied Artemia lakes has sodium group, the ratio of ions — type III ($HCO_3^- + SO_4^{2-} < Ca^{2+} + Mg^{2+}$, $Cl^- > Na^+$). Several lakes have water type II, which is often changed to III and vice versa. Individual lakes have type I (Borki).

The lake Ebeyty is characterized by transition from one class of salinity to another (sulfate ↔ sulfate-chloride ↔ chloride) during the season while there is intensive sedimentation of salt SO_4^{2+}.

For the period of investigation following lakes: Ebeyty, Novo-Georgievskoye, Umreshevo, Setovo, Vishnyakovskoye, Sulfatnoye, Sobachye, Siverga, Kulundinskoye, Malinovoye belonged to chloride class with II type of water ($HCO_3^- + SO_4^{2-} > Ca^{2+} + Mg^{2+}$).

Only one lake from studied reservoirs had type I of water with chloride class. This is Borki lake. In this lake bicarbonate and carbonate ions had the maximum concentrations among all studied lakes.

Two Artemia reservoirs Nevidim and Gashkovo have changeable type of water. In spring due to strong freshening lake brine had type II, to the end of summer it passed in type III. This pattern was observed for several years.

Chloride anions in the lake brine of majority lakes occupy dominant position. Their concentration exceeds significantly the content of sulfate anions occupying the second position in anionic composition. The maximum values of lake salinity are associated with high content of chlorine. Moreover, the chloride anions balance as cations of sodium and potassium, as magnesium. The maximum concentrations of chloride anions in some years reached values 121, 135, and 185 g/l (respectively, lakes Bolshoye and Maloye Medvezhye, Lavrushino, Ebeyty).

The maximum concentration of sulfate anions was observed in the lake Ebeyty. In 1997 it was 92 g/l, in 2001 — 107 g/l, in 2003 — 105 g/l, in 2004 — 88 g/l.

Carbonate and bicarbonate ions in comparison with other anions have low concentrations. The maximum concentrations of bicarbonates and carbonates were observed in lake Kurtamyshskoye — 5211 and 1452 mg/l (12 % of the total ions) and in lake Borki — 2581 and 960 mg/l, respectively (5 % of the total ions). Bicarbonate ions in concentration more than 1.0 g/l were contained in water from 11 % of surveyed lakes.

In cation composition ions of sodium and potassium dominate in lake brine. Total concentration of sodium and potassium cations during the period of observation in different lakes was in the range from 2.6 g/l (lake Siverga) and 7.4–7.7 g/l (Tauzatkul and Lavrushino) up to 95 g/l (Malinovoye lake) and

123 g/l (lake Ebeyty). All observed Artemia reservoirs had sodium group. The ratio Na^+/K^+ in water of surveyed lakes was in the range from 116 to 311.

Magnesium occupies the second position in cation composition of brine lakes. The range of variation of quantities of magnesium cations was from 59 (lake Kurtamyshskoye) till 20 124 mg/l (lake Lavrushino).

The content of calcium ions, which are essential element in crustacean life, in water of the most Artemia lakes was relatively high (40 to 2876 mg/l) and could not limit their needs. Minimum content of calcium cations (3 mg/l) was observed only in water of lake Kurtamyshskoye, maximum — 7916 mg/l in lake Lavrushino and 10 086 mg/l in lake Soleniy Kulat.

Due to high content of magnesium ions water is very hard (total hardness is 84–1740 suH/l). The lakes Kurtamyshskoye and Borki were exceptions where total hardness was respectively 5 and 15 suH/l, that is, it was significantly lower.

The acidity of lake brine over the period of investigations was in weakly alkaline part of pH-scale (7.5 to 8.5) for the most of reservoirs. The lowest pH values (6.8–7.1) were rearely fixed in the lakes Vishnyakovskoye, Soleniy Kulat and Lavrushino, the highest (from 9.1 to 9.5) were in the lakes Borki, Kurtamyshskoye, Cheder, Pervomayskoye and Tus. In general water in the lakes was differed by good buffer capacity.

The ratio of major ions in water of investigated lakes ranged widely (Tab. 2) and differed significantly from natural sea water. So the ratio Cl^-/SO_4^{2-} in sea water was 7, in water of investigated lakes (averaged data) it ranged from 0.47 to 296.38 and in average it was 13.02 ± 7.30 (C_v = 355 %). The minimum values of this index were marked for the lakes of Khakasia (0.47–0.68), the maximum was for lake Bolshoye Yarovoye. In earlier studies (1979–1984) on lake (Solovov, Studenikina, 1990) the ratio Cl^-/SO_4^{2-} was equal 104.43.

The ratio $Cl^-/(Na^+ + K^+)$ in seawater is 1.7. In studied lakes this indicator was relatively stable (0.36 to 1.94) and in average it was 1.15 ± 0.06 (C_v = 32 %). The ratio of Mg^{2+}/Ca^{2+} in sea water is equal to 3.2; in investigated lakes it was in the range from 4.97 to 125.74 and on average it was equal 34.65 ± 4.09 (C_v = 75 %). In five lakes (Filatovo, Lavrushino, Voskresenskoye, Communarskoye, Soleniy Kulat) this ratio was less than 10. It indicates relatively high content of Ca^{2+} ions. Only in one lake (Kulundinskoye) this ratio was higher than 100. In earlier studies (1979–1984) this ratio was equal to 33.3 (Solovov, Studenikina, 1990). The ratio $(Na^+ + K^+)/(Mg^{2+} + Ca^{2+})$ in seawater is equal to 6.6; in the lakes it is from 0.98 to 162.67 and in the average it is 9.92 ± 4.70 (C_v = 300 %). In the most lakes this indicator did not exceed 8, and only in three lakes: Borki, Kurtamyshskoye and Malinovoye it was 32.163 and 103 respectively.

The content of organic matter in studied lakes was judged by the amount of permanganate oxidation (PO) and biochemical oxygen demand during five days (BOD_5). The amount of permanganate oxidation of water characterizes the content of oxidizable organic matter. This indicator depends also on the chlo-

Table 2. **Ratio of concentrations of the main ions expressed in water of the investigated lakes (on average data)**

Lake	Cl^-/SO_4^{2-}	$Cl^-/(Na^+ + K^+)$	Mg^{2+}/Ca^{2+}	$(Na^- + K^-)/(Mg^{2+} + Ca^{2+})$	Na^-/K^-
M. Medvezhye	5.81	1.23	24.01	2.29	230
B. Medvezhye	5.85	1.24	24.15	2.27	270
Nevidim	2.87	1.16	32.58	2.07	179
Vishnyakovskoye	2.00	0.88	30.93	3.58	116
Aktoban	4.78	1.25	22.59	2.10	—
B. Kureynoye	6.14	1.36	36.93	1.77	—
Trebushinoye	4.82	1.42	11.86	1.55	—
Filatovo	9.92	1.63	6.78	1.33	—
Gashkovo	5.04	1.01	25.95	4.11	—
Setovo	4.52	1.05	73.14	3.67	—
Umreshevo	2.68	1.18	23.53	1.69	—
Shamelya	5.74	1.18	47.40	3.27	—
Sobachye	2.19	0.80	47.93	3.68	—
Lavrusheno	23.57	1.94	6.42	1.04	—
Voskresenskoye	12.23	1.55	4.97	1.49	—
N.-Georgievskoye	5.06	1.00	63.95	5.05	—
Aslykul	4.70	1.47	28.82	1.28	—
Cherdynskoye	6.80	1.13	63.08	3.63	—
Borki	2.01	0.66	10.57	31.84	—
Tibizkol	4.34	1.19	81.09	2.16	—
Shashmura	1.96	0.98	26.99	2.29	—
Lake N 1	2.38	1.06	38.01	2.13	—
Kurtamyshskoye	0.77	0.39	32.41	162.67	—
Solenoye 18 (Okunevo)	9.50	1.40	11.33	1.92	—
Siverga	3.11	1.08	39.45	4.37	—
Kommunarskoye	11.46	1.52	8.68	1.63	—
Okunevoye	9.39	1.27	28.39	2.69	—
Soleniy Kulat	18.19	1.89	5.43	0.98	—
Sosnovskoye	11.84	1.45	49.09	1.79	—
Bersenevskoye	6.83	1.45	12.00	1.59	—
Oktyabrskoye	6.10	1.35	37.18	1.72	—
Tauzatkul	7.06	1.37	13.91	1.86	—
B. Yarovoye	296.38	1.36	36.27	2.49	—
Kulundinskoye	2.52	0.76	125.74	3.68	—
Malinovoye	3.14	0.79	13.25	102.58	—
Ulzhay	5.71	1.18	28.02	2.75	—
Ebeyty	1.81	0.78	22.43	5.66	311
Tus	0.68	0.67	79.15	1.58	—
Cheder	0.47	0.36	32.40	7.72	—
Pervomayskoye	0.56	0.43	79.17	4.63	—
min	0.47	0.36	4.97	0.98	116
max	296.38	1.94	125.74	162.67	311
M	13.02	1.15	34.65	9.92	221.20
m	7.30	0.06	4.09	4.70	34.12
C_v	355	32	75	300	35
σ	46.19	0.37	25.87	29.70	76.44

ride content, so there is clear correlation between absolute value of permanganate oxidation and content of chlorine ions.

The range of changes in quantity of permanganate oxidation in Artemia lakes is quite wide — from 4.0 to 160.0 mgO/l. Values of permanganate oxidation above 100 mg/l were registered in lakes Maloye and Bolshoye Medvezhye, Ebeyty and Sobachye, below 10 mg/l — in lakes Octyabrskoye and Lavrushino.

The BOD_5 value correlates with size of permanganate oxidation. During the period of researches values of BOD_5 were in the range from 0.2 (Setovo) to 19.2 mgO_2/l (Soleniy Kulat). The BOD_5 values for the most Artemia lakes were within 2–8 mgO_2/l.

The content of biogenic elements in Artemia lakes in the most cases was low and it was ranged from analytical zero to hundredth — tenth mg/l, but in some cases it has attained concentration 1 mg/l and above (Tab. 3). The amount of nitrogen nitrites in the most of studied lakes was thousandths and hundredths mgN/l, and only in lake Umreshevo (24.05.2002) it reached values 0.3 mgN/l. It was apparently due to pollution of the reservoir with organic wastes in May.

Table 3. **Average and limiting concentration of biogenic elements in lakes for the period researches (2002–2004), mg/l**

Lake	Statistics	$N—NO_2^-$	$N—NO_3^-$	PO_4^{3-}	Fe_{total}
1	2	3	4	5	6
Siverga	*M*	0.002	0.063	0.339	—
Solenoye 18	*M*	0.004	0.008	0.173	—
Cherdynskoye	min	0.001	0.008	0.250	—
	max	0.008	0.017	0.729	—
N.-Georgievskoye	*M*	0.0023	0.012	0.335	—
	min	0	0.003	0.063	0.058
	max	0.008	0.029	1.010	2.505
B. Medvezhye	*M*	0.0035	0.014	0.541	1.281
	min	0	0	0.161	0.071
	max	0.088	0.24	1.500	0.212
M. Medvezhye	*M*	0.008	0.023	0.599	0.133
	min	0	0	0.186	0.047
	max	0.021	0.105	1.429	0.179
Filatovo	*M*	0.005	0.027	0.649	0.106
	min	0	0	0.098	—
	max	0.003	0.019	0.194	—
Nevidim	*M*	0.0015	0.0095	0.141	—
	min	0	0	0.116	0.232
	max	0.059	0.033	1.161	0.578
Umreshevo	*M*	0.0095	0.0125	0.412	0.397
	min	0.003	0.007	0.123	—
	max	0.3	0.323	0.186	—
B. Kureynoye	*M*	0.1515	0.165	0.154	—
	min	0	0.004	0.106	0.014
	max	0.043	0.053	0.286	0.026
Trebushinoye	*M*	0.017	0.027	0.208	0.02
	min	0	0.004	0.197	0.219
	max	0.021	0.037	1.145	1.927
Sobachye	*M*	0.008	0.021	0.452	1.073
Vishnyakovskoye	*M*	0.001	0.007	0.248	—
	min	0	0.008	0.453	0.03
	max	0.033	0.066	1.128	0.062
	M	0.0141	0.024	0.591	0.046

Table 2. **Ratio of concentrations of the main ions expressed in water of the investigated lakes (on average data)**

Lake	Cl^-/SO_4^{2-}	$Cl^-/(Na^+ + K^+)$	Mg^{2+}/Ca^{2+}	$(Na^- + K^-)/(Mg^{2+} + Ca^{2+})$	Na^-/K^-
M. Medvezhye	5.81	1.23	24.01	2.29	230
B. Medvezhye	5.85	1.24	24.15	2.27	270
Nevidim	2.87	1.16	32.58	2.07	179
Vishnyakovskoye	2.00	0.88	30.93	3.58	116
Aktoban	4.78	1.25	22.59	2.10	—
B. Kureynoye	6.14	1.36	36.93	1.77	—
Trebushinoye	4.82	1.42	11.86	1.55	—
Filatovo	9.92	1.63	6.78	1.33	—
Gashkovo	5.04	1.01	25.95	4.11	—
Setovo	4.52	1.05	73.14	3.67	—
Umreshevo	2.68	1.18	23.53	1.69	—
Shamelya	5.74	1.18	47.40	3.27	—
Sobachye	2.19	0.80	47.93	3.68	—
Lavrusheno	23.57	1.94	6.42	1.04	—
Voskresenskoye	12.23	1.55	4.97	1.49	—
N.-Georgievskoye	5.06	1.00	63.95	5.05	—
Aslykul	4.70	1.47	28.82	1.28	—
Cherdynskoye	6.80	1.13	63.08	3.63	—
Borki	2.01	0.66	10.57	31.84	—
Tibizkol	4.34	1.19	81.09	2.16	—
Shashmura	1.96	0.98	26.99	2.29	—
Lake N 1	2.38	1.06	38.01	2.13	—
Kurtamyshskoye	0.77	0.39	32.41	162.67	—
Solenoye 18 (Okunevo)	9.50	1.40	11.33	1.92	—
Siverga	3.11	1.08	39.45	4.37	—
Kommunarskoye	11.46	1.52	8.68	1.63	—
Okunevoye	9.39	1.27	28.39	2.69	—
Soleniy Kulat	18.19	1.89	5.43	0.98	—
Sosnovskoye	11.84	1.45	49.09	1.79	—
Bersenevskoye	6.83	1.45	12.00	1.59	—
Oktyabrskoye	6.10	1.35	37.18	1.72	—
Tauzatkul	7.06	1.37	13.91	1.86	—
B. Yarovoye	296.38	1.36	36.27	2.49	—
Kulundinskoye	2.52	0.76	125.74	3.68	—
Malinovoye	3.14	0.79	13.25	102.58	—
Ulzhay	5.71	1.18	28.02	2.75	—
Ebeyty	1.81	0.78	22.43	5.66	311
Tus	0.68	0.67	79.15	1.58	—
Cheder	0.47	0.36	32.40	7.72	—
Pervomayskoye	0.56	0.43	79.17	4.63	—
min	0.47	0.36	4.97	0.98	116
max	296.38	1.94	125.74	162.67	311
M	13.02	1.15	34.65	9.92	221.20
m	7.30	0.06	4.09	4.70	34.12
C_v	355	32	75	300	35
σ	46.19	0.37	25.87	29.70	76.44

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	max	0.088	0.24	1.500	0.212
	M	0.008	0.023	0.599	0.133
M. Medvezhye	min	0	0	0.186	0.047
	max	0.021	0.105	1.429	0.179
	M	0.005	0.027	0.649	0.106
Filatovo	min	0	0	0.098	—
	max	0.003	0.019	0.194	—
	M	0.0015	0.0095	0.141	—
Nevidim	min	0	0	0.116	0.232
	max	0.059	0.033	1.161	0.578
	M	0.0095	0.0125	0.412	0.397
Umreshevo	min	0.003	0.007	0.123	—
	max	0.3	0.323	0.186	—
	M	0.1515	0.165	0.154	—
B. Kureynoye	min	0	0.004	0.106	0.014
	max	0.043	0.053	0.286	0.026
	M	0.017	0.027	0.208	0.02
Trebushinoye	min	0	0.004	0.197	0.219
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Sobachye	*M*	0.001	0.007	0.248	—
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	max	0.033	0.066	1.128	0.062
	M	0.0141	0.024	0.591	0.046

Table 3 (continued)

1	2	3	4	5	6
Aktoban	min	0	0.007	0.104	—
	max	0.009	0.066	0.413	—
	M	0.0043	0.024	0.254	0.03
Voskresenskoye	min	0	0.002	0.019	0.036
	max	0.005	0.096	0.067	0.279
	M	0.0028	0.0398	0.043	0.157
Gashkovo	min	0	0.004	0.446	0.036
	max	0.014	0.013	0.722	0.087
	M	0.0046	0.0081	0.550	0.061
Setovo	*M*	0	0.005	0.034	—
Borki	min	0	0.003	0.034	—
	max	0.002	0.005	4.440	—
	M	0.001	0.004	2.237	—
Shamelya	min	0	0.004	0.092	0.033
	max	0	0.016	0.101	0.033
	M	0	0.01	0.0965	0.033
Lavrusheno	*M*	0.002	0.001	0.107	—
Aslykul	min	0.002	0.001	0.107	—
	max	0.023	0.014	0.116	—
	M	0.0125	0.0075	0.1115	—
Oktyabrskoye	*M*	0	0.004	0.122	—
Soleniy Kulat	min	0.002	0.014	0.03	—
	max	0.033	0.353	0.115	—
	M	0.017	0.139	0.077	—
Tauzatkul	*M*	0	0.008	0.378	—
Ulzhay	min	0	0.004	0	0.012
	max	0.007	0.034	0.304	0.186
	M	0.0031	0.013	0.161	0.114
Ebeyty	min	0	0.007	0.374	0.01
	max	0.03	0.139	2.857	0.165
	M	0.011	0.039	1.071	0.073

The content of nitrate nitrogen, the main source of nutrients for plants in the most of the samples was at the level of hundredths and tenths mgN/l and ranged from 0 to 0.35 mgN/l. Phosphates have concentrations from 0 mg/l (Ulzhay) to 4.44 mg/l (Borki) in mineral lake water. In the most lakes their content does not exceed a few tenths of mgP/l. Total iron was in the range from 0.01 to 2.5 mg/l.

In general the best supply of biogenic nitrogen was observed in the lakes Bolshoye Medvezhye, Umreshevo, Soleniy Kulat; nutrient phosphorus was in the lakes Borki, Ebeyty, Novo-Georgievskoye, Trebushinoye; biogenic iron was in the lakes Novo-Georgievskoye and Trebushinoye.

2.3.1.2. Seasonal dynamics of salt composition of water

The composition of ions and total mineralization of water in Artemia lakes constantly change under influence of hydrometeorological conditions. These changes, depending on duration of action, can be cyclic or seasonal and periodic or climate. Generally at cyclic changes the lowest salt concentration is observed in spring (during melting of snow and ice) and the highest one is at the end of summer or in winter. The amplitude of brine concentration during annual cycle, according to A.I. Dzens-Litovskiy (1968), reaches more than 240 g/l, however, heavy rains just in a few hours can dilute the concentration of brine at 100–170 g/l.

Annual dynamics of salt composition of water, traced on the example of several model lakes (Fig. 9) during 2000–2004, is characterized by significant decrease of all ions in the period from March to April (average in 3 or more times), fast recovery of the concentration of all ions to May — June and relative constancy of chemical composition from June to February. Slight increase in quantity of mineralization is observed at the end of August — beginning of September (or rearely in winter). After that there is a decrease of this indicator again due to dilution of autumn rain water and settling-out of salts. This process is connected with temperature changes. In abounding in water years during melting of snow in some lakes water is almost fresh (poorly salt water). It was observed in 2002 in the lakes: Novo-Georgievskoye, Aktoban, Gashkovo. But by the end of April the magnitude of salinity increased from 1.0–3.0 to 11.0–48.0 g/l.

In Fig. 9, showing the dynamics of water salinity for four years, it is clearly shown that the salinity of high-mineralized lakes (Ebeyty, Maloye and Bolshoye Medvezhye) in 2001 was mainly above optimum for Artemia development, in 2002–2004 it was within the optimum. Salinity of the lakes with average mineralization (Nevidim, Vishnyakovskoye, Ulzhay) in 2001 was within the optimum, in 2002–2004 it was mostly below the optimum.

Analysis of monitoring data for 2000–2004 showed characteristic dynamics of deviation of salinity values from January to December from the mean seasonal indices (Fig. 10). The figure shows that the values of salinity, which are the most closely matched to mean season, are in July — August and November, the least — in April. Variability (App. 5) of relative salinity is the highest in March — April and September ($C_v > 50$ %); the lowest — in June — July (C_v less than 10 %).

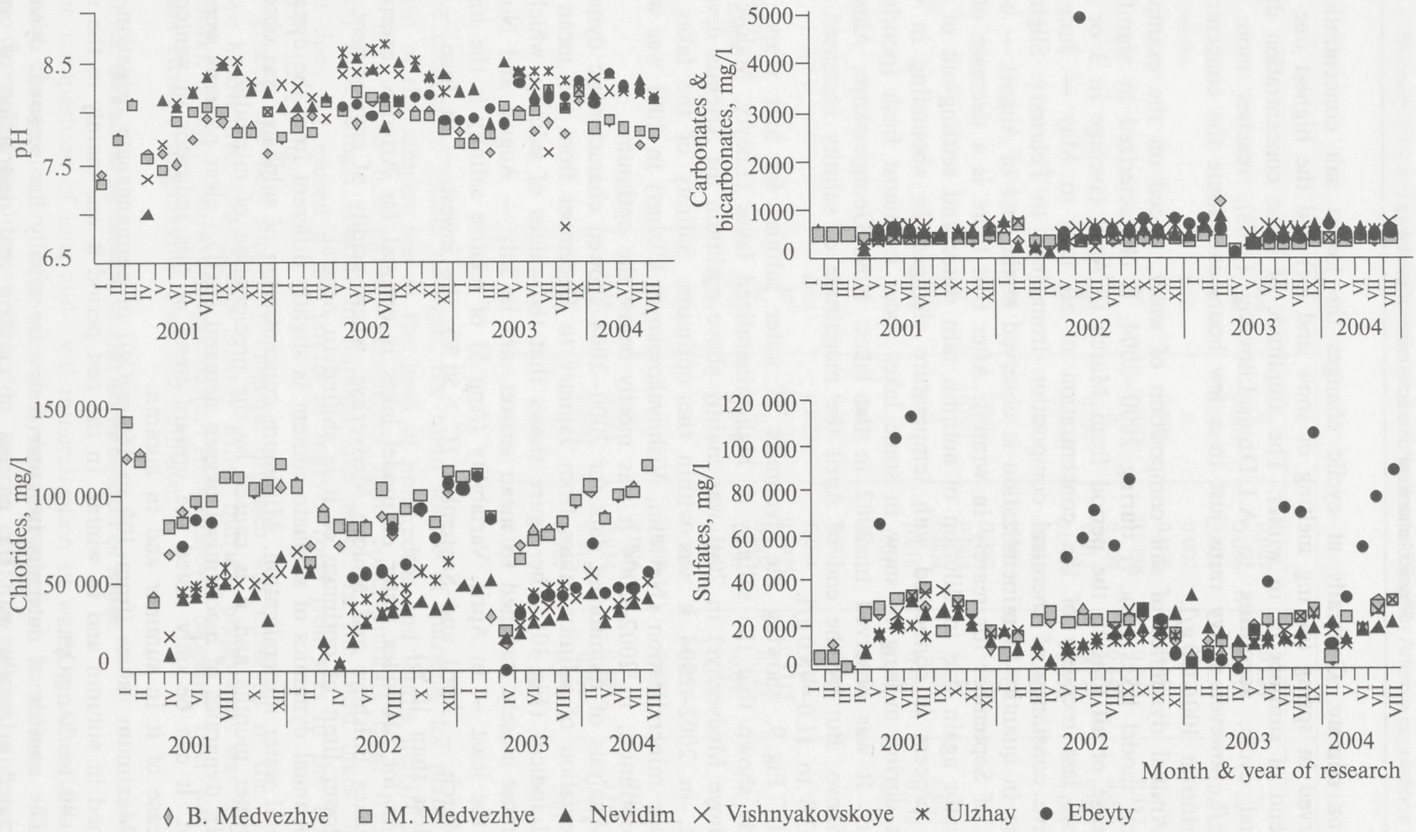
As for pH-index water of model lakes is optimal for Artemia, except for the lakes Bolshoye and Maloye Medvezhye, where acidity of environment is at the lower limit of optimum or it is shifted to neutral.

Annual dynamics of sulphate content is slightly different from the dynamics of total water mineralization. Minimum concentration of sulphates was observed in winter months and it is caused by the precipitation of mirabilite.

In dynamics of biochemical oxygen demand (BOD_5) clear patterns were not found. It can be only noted the upward trend of this indicator in winter and decrease of it in summer and in autumn.

Maximum values (from 100 to 160 mgO/l) of permanganate oxidation were reached in autumn and in winter. In the rest period it was mainly in the range from 40 to 70 mgO/l.

The content of nutrients in water reservoirs usually has seasonal dynamics associated primarily with the process of creation and destruction of organic



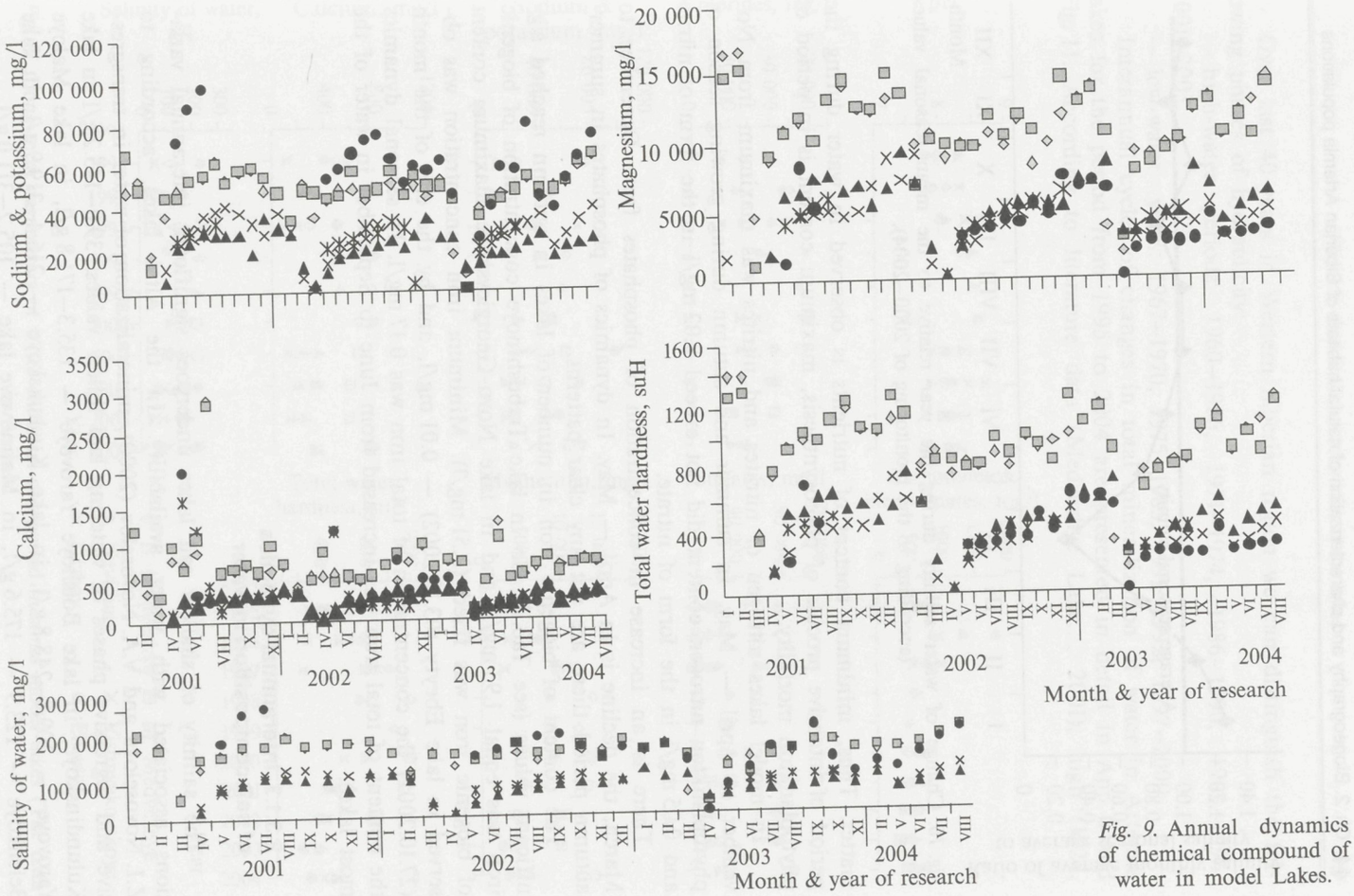


Fig. 9. Annual dynamics of chemical compound of water in model Lakes.

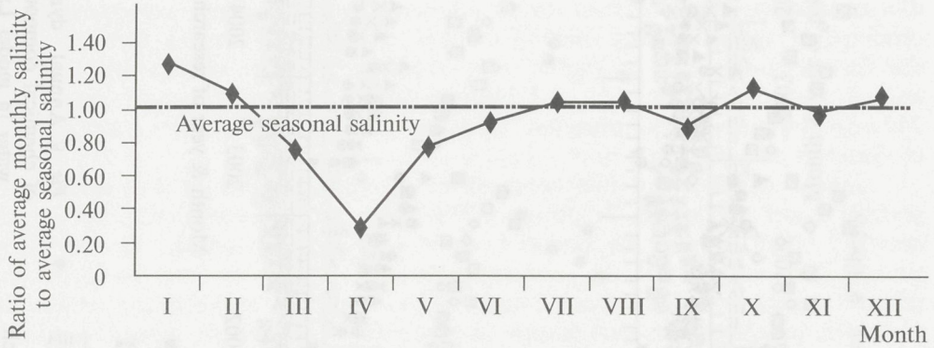


Fig. 10. Change of water salinity during the year relative to the mean seasonal values (according to the monitoring of 2000–2004).

matter. Thus, minimum content of nutrients is observed in water during the period of intensive process of photosynthesis, maximum content is in period of phytoplankton mortality.

In model lakes nitrogen of nitrates and nitrites was maximum from November to April — May. In summer and autumn during growing season of phytoplankton nitrogen content did not exceed 0.02 mg/l in the form of nitrite and 0.05 mg/l in the form of nitrate.

There is an increase in concentration of phosphates from December to March, the decline is in April — May. In dynamics of phosphates in summer-autumn period there are not any clear patterns.

The content of biogenic iron in number of lakes in autumn reached significant values (see Tab. 3). So in lake Trebushinoye concentration of biogenic iron was equal 1.93 mg/l, and in lake Novo-Georgievskoye maximum content of biogenic iron was fixed (2.51 mg/l). Minimum iron concentration was observed in lake Ebeyty (03.10.2002) — 0.01 mg/l, and by the end of the month (27.10.2002) the concentration of total iron was 0.17 mg/l. In seasonal dynamics the content of total iron was increased from June to September in water of the most lakes.

2.3.1.3. Interannual dynamics of salt composition in water

The salinity of shallow salt lakes undergoes significant interannual variations associated with water availability. In the Altai lakes, according to Z.I. Novoselova and V.A. Novoselov (2000), mineralization of water in transgressive and regressive phases of watering had follow values: 39.0–145.2 g/l in lake Kulundinskoye, in lake Bolshoye Yarovoye — 135.3–171.8 g/l, in lake Maloye Yarovoye — 209.8–248.8 g/l, in lake Kuchukskoye — 216.4–319.9 g/l, in lake Belenkoye — 123.9 — 175.6 g/l, in Malinovoye lake — 105.2–311.0 g/l.

Over last 40 years in Western Siberian region we can distinguish the following phases of hydraulicity:

— high-water periods: 1960–1966, 1971–1974, 1986–1990, 1993–1996, 2001–2003;

— low-water years: 1967–1970, 1975–1985, 1991–1992, 1997–2000.

Interannual cycles of changes in total mineralization of water in Artemia lakes for the period from 1995 to 2004 are presented in detail in App. 6 and Fig. 11. According to literature data (Medvezhye Lake..., 2001), high (1928,

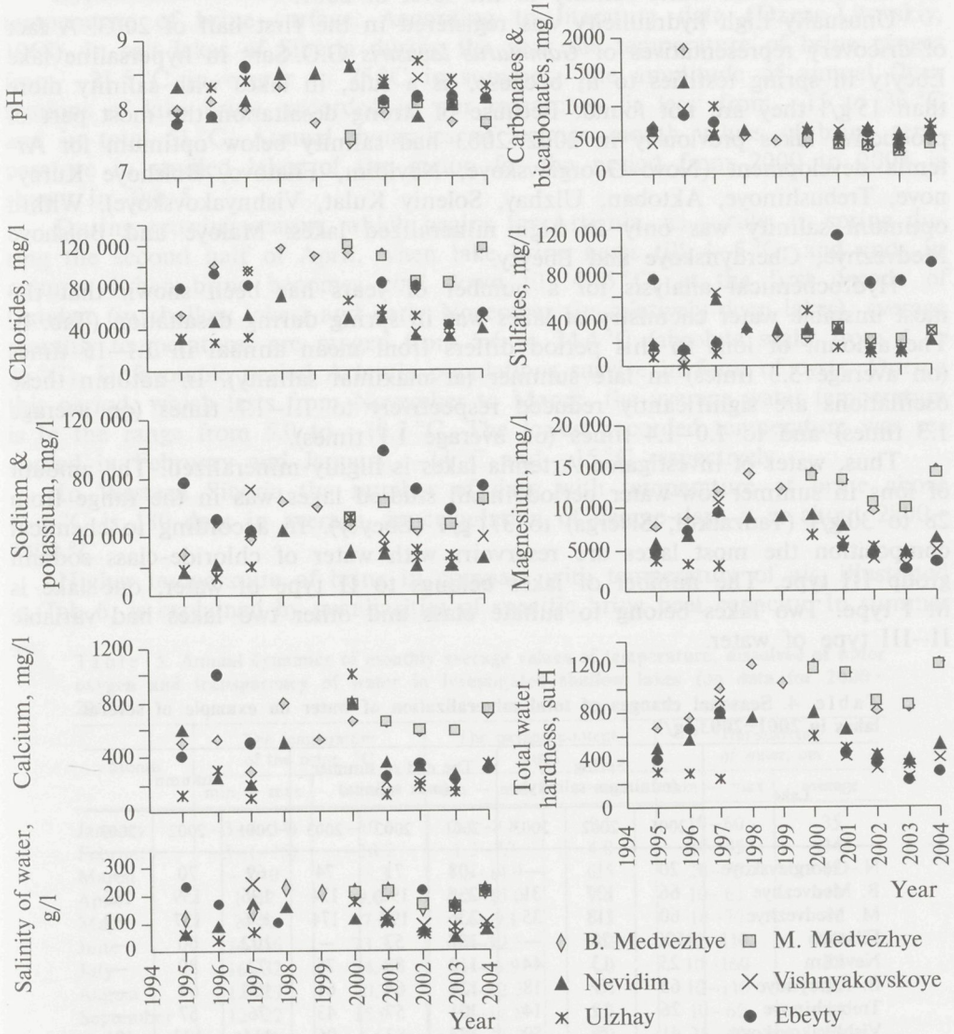


Fig. 11. Long-term parameters of water chemical compound in some model lakes (The data in August).

1950, 1971, 1995) and low-water (1969, 1975, 1982–1992) years were characterized respectively by low and high salt content with difference in ion concentration up to 4 times. For ten-year research period maximal salinity was recorded in 1998 and 2000, minimum was in 1995 and 2003. From 1995 to 2000 there was an increase of water salinity on average 1.7 times. Since 2001 there was an increase of hydraulicity and the amount of mineralization declined again. So in 2001, 2002 and 2003 salinity in the lakes decreased in compare with 2000, respectively, on average 14.44 and 49 % for all lakes. In 2004 there was an increase in water salinity to the level of 2001.

Unusually high hydraulicity was registered in the first half of 2003. A fact of discovery representatives of *Gammarus lacustris* G.O. Sars in hypersaline lake Ebeyty in spring testifies to it, because, as a rule, in lakes with salinity more than 15 g/l they are not found. Because of strong desaltation the most part of productive lakes previously in 2002–2003 had salinity below optimum for Artemia development (Novo-Georgievskoye, Nevidim, Filatovo, Bolshoye Kureynoye, Trebushinoye, Aktoban, Ulzhay, Soleniy Kulat, Vishnyakovskoye). Within optimum salinity was only in high mineralized lakes: Maloye and Bolshoye Medvezhye, Cherdynskoye and Ebeyty.

Hydrochemical analysis for a number of years has been shown that the most unstable water chemistry of lakes was in spring during desaltation (Tab. 4). The amount of ions in this period differs from mean annual in 1.1–15 times (on average 3.3 times) in late summer (at maximal salinity). In autumn these oscillations are significantly reduced respectively to 1.1–1.7 times (on average 1.3 times) and to 1.0–1.4 times (on average 1.1 times).

Thus, water of investigated Artemia lakes is highly mineralized. The amount of ions in summer low-water period in all studied lakes was in the range from 28 to 30 g/l (Tauzatkul, Siverga) to 371 g/l (Ebeyty). In according to chemical composition the most lakes are reservoirs with water of chloride-class sodium group III type. The number of lakes belongs to II type of water, one lake is in I type. Two lakes belong to sulfate class and other two lakes had variable II–III type of water.

Table 4. **Seasonal changes of total mineralization of water on example of several lakes in 2001–2003, g/l**

Lake	Spring (minimum salinity)			The end of summer (max salinity)			Autumn		
	2001	2002	2003	2001	2002	2003	2001	2002	2003
N.-Georgievskoye	20	1	—	108	71	74	69	70	—
B. Medvezhye	66	137	31	230	192	174	196	159	185
M. Medvezhye	60	118	35	236	194	174	196	157	189
Filatovo	100	20	—	137	57	—	102	60	—
Nevidim	25	13	44	113	88	76	73	80	—
B. Kureynoye	63	8	18	124	64	61	100	64	—
Trebushinoye	26	12	14	101	57	43	76	57	—
Vishnyakovskoye	41	5	59	132	83	96	114	102	101
Aktoban	57	2	—	107	62	—	88	70	—
Gashkovo	—	3	—	84	65	—	84	71	—

High salinity of water in Artemia lakes is a result of high content of chloride, sulfate, sodium and magnesium ions. Water in the lakes is characterized by high hardness, associated, mainly, with the presence of magnesium cations, weakly alkaline or alkaline pH, high content of organic substances, presents of number of nutrients which are sufficient for photosynthesis.

2.3.2. Features of lake thermal regime

Hyperhaline Artemia lakes are characterized by large amplitude of annual temperature of brine surface. According to literature data (Dzens-Litovskiy, 1968), in salt lakes of Siberia during the year the temperature of brine ranges from –21.5 °C in winter to 75 °C in summer. The amplitude of annual fluctuations of lake brine, recorded in our researches, is less: from –15 to 36 °C and in total 51 °C. Annual dynamics of average month values of brine temperature in studied lakes of the region for the period from 2000 to 2004 is shown in Tab. 5.

During growing season, which begins for Artemia, as a rule, in spring during the second half of April, when lake brine heats till 4–5 °C, and ends in autumn (when brine becomes cool down till 4–5 °C) at the first decade of October (in shallow lakes) and early November (in relatively deep lakes), average monthly temperatures are ranged from 5.6 to 24.4 °C (absolute scale: from 4 to 36 °C). Unfavorable period Artemia populations survive in form of cysts. During this period, which lasts from November to March, the average water temperature is in the range from 5.0 to –10.2 °C. The lowest recorded temperature was recorded in February and January, –14 °C and –15 °C respectively.

In Western Siberia the number of days with temperature of brine above 4–5 °C is 180 days in average, in calculation of degree-days it is about 2800–3400 °C.

Higher temperature of brine in compare with temperature of air, illustrated in Tab. 6, is explained by peculiarities of specific brine heat capacity. In summer

Table 5. **Annual dynamics of monthly average values of temperature, dissolved of water oxygen and transparency of water in investigated shallow lakes (on data for 2000–2004)**

Month	The temperature of the brine, °C		The oxygen content, mg/l		Transparency of water, cm	
	min — max	average	min — max	average	min — max	average
January	–3–(–14)	–10.1	2.4–8.8	5.1	10–60	35
February	–5–(–15)	–10.2	1.3–7.7	4.0	20–45	34
March	–5–0	–3.3	1.5–14.9	6.5	20–70	42
April	1–17	9.6	4.5–15.0	7.6	10–65	40
May	2–21	17.1	1.6–9.1	5.3	10–70	41
June	14–36	23.3	0.8–12.8	5.2	10–110	53
July	16–32	24.4	1.4–6.9	4.0	10–160	57
August	12–29	20.7	1.7–12.3	5.4	10–110	52
September	12–22	15.9	1.7–12.8	5.2	10–60	44
October	2–12	5.6	1.8–11.2	5.9	25–80	52
November	3–7	5.0	2.7–9.8	4.6	40–70	55
December	–5–(–13)	–9.4	1.8–5.8	3.9	20–60	40

Table 6. **Dynamics of monthly average temperature of Artemia lakes brines for the long-term period, °C**

Lake	Months of the year											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Deeper lakes of Altai												
Bolshoye Yarovoye[1]	—	—	—	6.6	13.4	19.4	21.7	20.7	14.9	9.0	—	—
Kulundinskoye[1]	—	—	—	11.8	16.3	20.5	21.8	19.1	12.4	4.7	—	—
Air temperature[2, 3]	−19.7	−18.4	−12.1	−1.3	9.8	20.5	21.8	19.1	12.4	1.0	−9.5	−17.0
	−18.9	−18.2	−10.6	3.0	12.5	18.9	20.8	17.6	11.8	3.0	−7.8	−15.9
Shallow lakes of the Kurgan region												
Average values for 24 lakes	−11.3	−10.8	−3.8	10.6	17.0	21.9	24.0	21.1	16.2	5.3	4.7	−9.9
Air temperature[4, 5]	−17.0	−15.5	−9.0	2.5	11.0	17.0	18.6	16	10.5	2.0	−7.5	−14.5
	−17.7	−16.6	−8.6	4.1	12.6	17.2	19.1	16.3	10.9	2.4	−7.2	−14.3
Shallow lakes of the Omsk region												
Ebeyty and Ulzhay	−14.0	−10.5	—	2.5	14.2	21.5	24.8	21.9	15.5	5.2	−6.0	—
Air temperature[6, 7]	−19.2	−18.2	−11.6	0.7	11.3	17.0	19.1	16.4	10.7	1.8	−8.6	−16.3
	−19.0	−17.6	−10.2	2.8	11.4	17.1	18.9	15.8	10.6	1.9	−8.5	−16.0

Note. [1] According to Altay branch of Gosrybcentr; [2] Slyadnev, 1965; [3] SNiP 23-01-99, 2000 (Republic Altai, Slavgorod); [4] Geography of Kurgan region, 1993; [5] SNiP 23-01-99, 2000 (Kurgan); [6] Agroclimatic resources of the Omsk region, 1971; [7] SNiP 23-01-99, 2000 (Omsk).

the temperature of brines is higher than temperature of air, and, especially, the temperature of freshwater lakes as because of the ability of brines to absorb heat rays better than fresh water so because of increased absorption of rays by black silts. The layer of fresh water, formed in brine after rains, creates a kind of "greenhouse" effect, followed by heating of lower layers of brine. In relatively deep lakes because of absence of convection, the temperature at the bottom can be below 0 °C even in summer (Dzens-Litovskiy, 1968).

As temperatures drop in autumn and winter periods, the density of surface brine increases, and this layer sinks to the bottom. As in salt water a law about the greatest density of water at 4 °C does not work, typical for fresh water, the temperature of brine in winter can drop to −21.7 °C (Dzens-Litovskiy, 1968). In the lake Medvezhye the lowest recorded temperature was −19 °C (Medvezhye Lake..., 2001). Therefore, the temperature of brine in winter time is always below than the temperature of fresh water, but because of large heat capacity it is higher than the temperature of air.

It is known (Dzens-Litovskiy, 1968) that salinity 24.7 % is critical for formation of ice. From investigated lakes such salinity in winter in some years was observed in the lakes Ebeyty, Maloye and Bolshoye Medvezhye. Moreover, in winter 2002–2003 salinity in these lakes was lower. In winter due to decreasing freezing point of brine, Artemia lakes are not covered by ice for a long time. Ice cover, if it is formed, has a small thickness (15–20 cm) and friable structure. At the same time in winter brine cools down to −10 °C in average. The oscillation amplitude of absolute temperatures in winter time is equal to 10 °C. During this period lake platforms opened from snow and ice were observed only in central parts of the lakes Medvezhye and Ebeyty.

In spring (March — May) there is a large temperature differential (in general, 26 °C): from −5 °C in March to 21 °C in May. Average monthly temperatures in March were still negative (−3.3 °C), in April and May they were positive, respectively 9.6 and 17.1 °C. In the second half of April at positive water temperature water area of majority of investigated lakes was completely free from ice and snow.

The absolute values of water temperature in summer months ranged from 12 to 36 °C, average: in June — 23.3, in July — 24.4, in August — 20.7 °C.

In autumn the temperature of water decreased significantly and in September it had values from 12 to 22 °C (average 15.9 °C), in October — from 2 up to 12 °C (in average 5.6 °C), in November — from 3 to 7 °C (average 5 °C).

Annual dynamics of average monthly values of water temperature during the period from 2000 to 2004 in all studied shallow lakes is shown in Fig. 12.

From figure it is visible that for all lakes, in general, the period of Artemia existence limited to low temperature limitation (4–5 °C), it lasts from mid April to the end of October. Optimal temperature period for growth and reproduction is during three summer months. In 2000 water temperature in the lakes in June reached upper limit of Artemia existence.

Daily temperature fluctuations of brine in lake Medvezhye (data 2000) were shown in Fig. 13. The lowest temperature of brine was observed in predawn hours. The highest heating of water was in period from 3 to 6 o'clock am. Maximal fluctuations in daily temperature recorded in September were equal to 9 °C. Relatively constant temperature is characterized for July and August (the scale is not exceeded 4 °C).

Temperature regime of relatively deep Bolshoye Yarovoye has own characteristics of this lake. The surface layer of brine of the lake warms up in spring

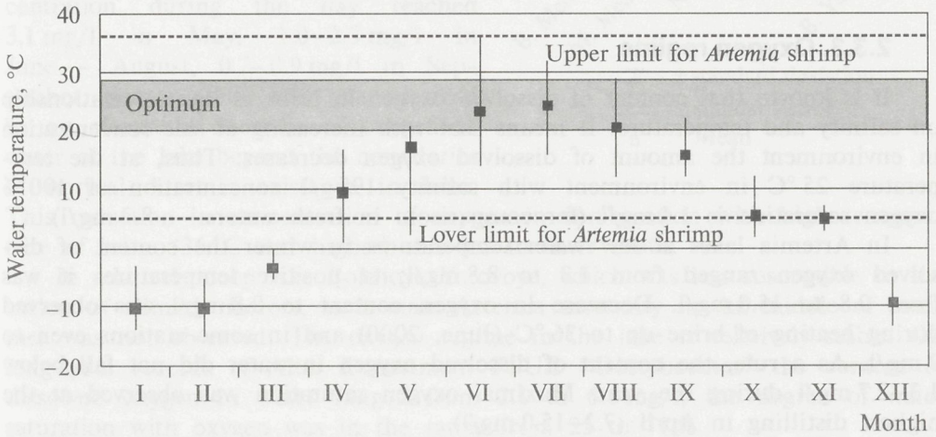


Fig. 12. Annual dynamics of average monthly values of temperature in the investigated lakes during 2000–2004.

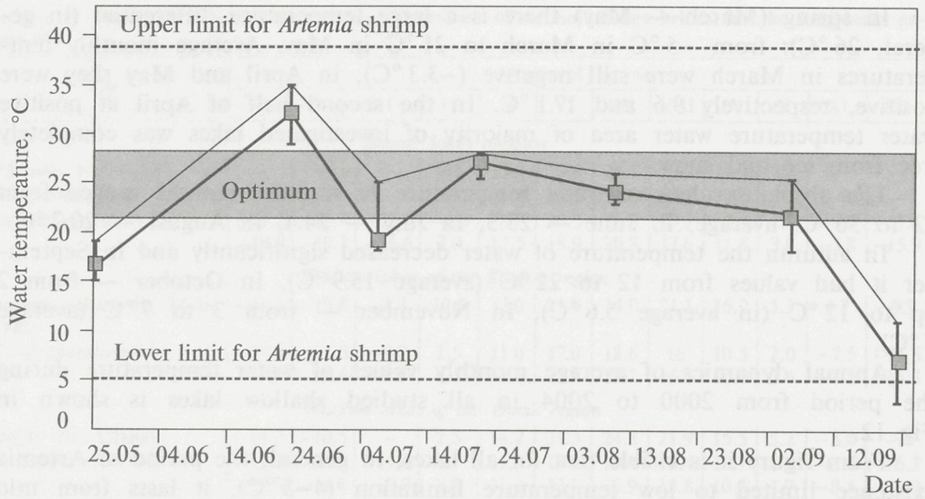


Fig. 13. Daily water temperature in Medvezhye Lake during the growing season in 2000.

and cools in autumn slower than in shallow lakes (see Tab. 6). According to data of Altay Department FSUE "Gosrybcenter" and Society of Limited Liability (SLL) "Arsal" (03.07.2001), temperature stratification is traced clearly with increasing of depth. So at depth 0–0.5 m temperature was equal 18.9 °C, at depth 2.0 m — 18.3 °C, at depth 3.5–4.0 m — 8.5 °C, at depth 6.0 m — 3.1 °C, at a depth 8.0–9.0 m — minus 5.6 °C. Thus, in mid-summer the temperature of brine at significant depth had negative values.

A comparative analysis of temperature data for 2002 was shown (Fig. 14*A*) that temperature of surface water layer in relatively deep lake Bolshoye Yarovoye had little different from temperature of water in shallow lakes.

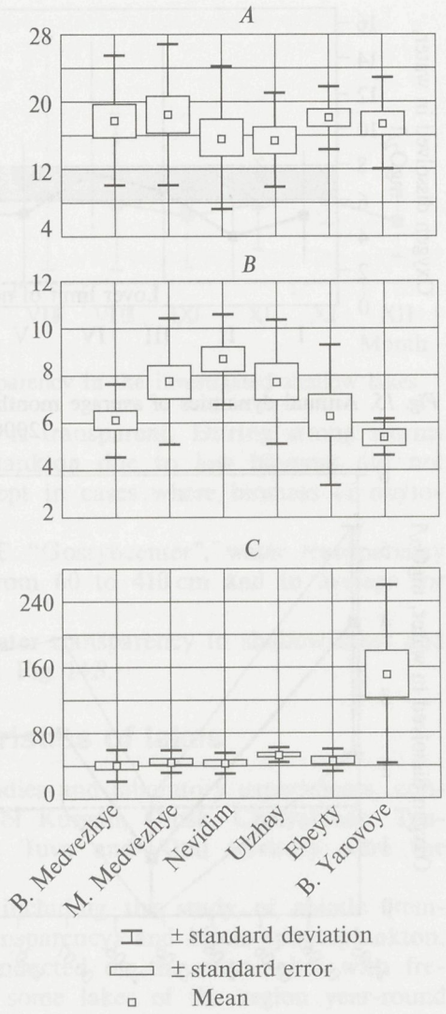
2.3.3. Oxygen regime

It is known that content of dissolved oxygen in brine is inverse relationship on salinity and temperature. It means that with increasing of salt concentration in environment the amount of dissolved oxygen decreases. Thus, at the temperature 25 °C in environment with salinity 195 g/l concentration of 100 % oxygen saturation is 1.4 mg/l (for comparison: in fresh waters — 8.2 mg/l).

In Artemia lakes at low water temperatures in winter the content of dissolved oxygen ranged from 1.3 to 8.8 mg/l; at positive temperatures it was from 0.8 to 15.0 mg/l. Decrease in oxygen content to 0.8 mg/l was observed during heating of brine up to 36 °C (June, 2000) and in some stations even to 0 mg/l. As a rule, the content of dissolved oxygen in water did not fall below 1.3–2.7 mg/l during the year. Maximal oxygen saturation was observed at the highest distilling in April (7.2–15.0 mg/l).

On Fig. 15 it is shown that the annual content of dissolved oxygen in water was above the lowest limit of normal Artemia existence (1.5 mg O_2/l). Mean

Fig. 14. Mean annual temperature (*A*, °C) and the concentration of dissolved oxygen (*B*, mg/l) and water transparency (*C*, m) in 2002.



monthly values of dissolved oxygen in water during the whole season in studied lakes were closed to optimal for development and reproduction of crustaceans and ranged from 4.0 (in July) to 7.6 (in April) mgO_2/l. Thus, at maximal water heating and the highest salinity content of oxygen dissolved in water was minimal. At the lowest water salinity and relatively low temperatures mean monthly values of oxygen were maximal. To confirm this pattern correlation analysis was conducted which had shown negative significant correlation of average force between the content of dissolved in water oxygen and salinity ($r = -0.393$, $n = 251$) and the absence of relationship between oxygen content and water temperature ($r = 0.067$, $n = 251$).

Dynamics of values of dissolved oxygen in water during the day was investigated in the lake Medvezhye in 2000 (Fig. 16). Change of oxygen concentration during the day reached 3.1 mg/l in May, 1.0–2.3 mg/l in June — August, 0.7–0.9 mg/l in September. Season 2000 was characterized by an abnormal decrease of oxygen in water of the lake beyond the boundaries of normal Artemia existence in June. This reduction in concentration of oxygen in combination with high temperature of brine (36 °C and higher) was led to their death.

In relatively deep lake Bolshoye Yarovoye, which was less susceptible to the action of climatic factors, such mass Artemia mortality in the middle of summer was not observed. The oxygen regime in the lake is relatively stable. On long-term records of Altai Department FSUE "Gosrybcenter" the content of dissolved oxygen in water ranged from 2.1 to 6.5 mg/l, the degree of water saturation with oxygen was in the range from 25 to 71 %.

The relative stability of the oxygen regime in deep lake is illustrated in Fig. 14*B*.

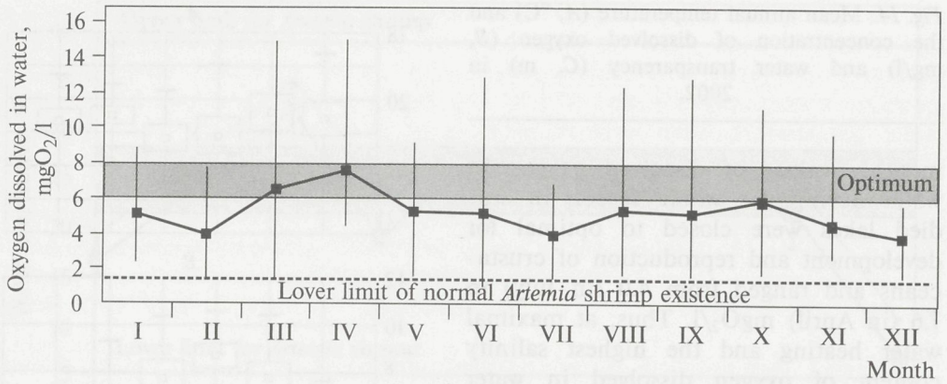


Fig. 15. Annual dynamics of average monthly values of dissolved oxygen for the period from 2000 to 2004.

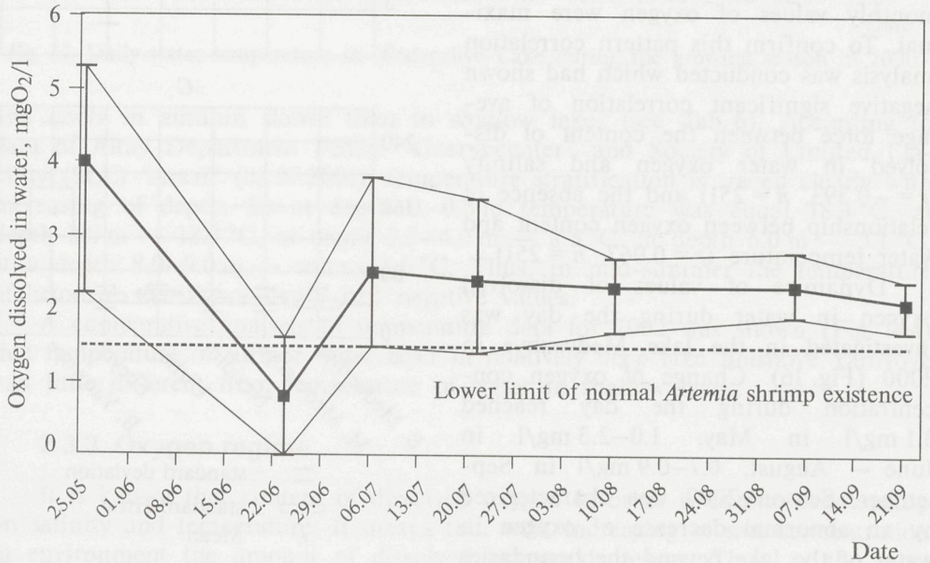


Fig. 16. Daily changes in the concentration of dissolved oxygen in Medvezhye Lake in 2000 during the growing season.

2.3.4. Water transparency

Water in studied lakes was mostly transparent. For the period of investigations water transparency in shallow lakes was in the range from 10 to 160 cm. Average monthly volues of transparency were equal 34–57 cm (Fig. 17), the average for the season — 40–55 cm. If it is considered that the depth of the most shallow lakes is typically 50–100 cm, the transparency was often to the bottom.

Water transparency in shallow lakes with large amount of organic matter accumulated on the bottom and silts depends on wind mixing. In sunny

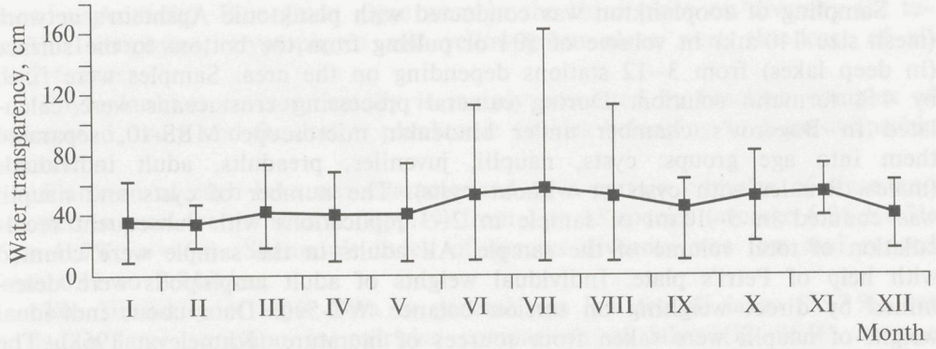


Fig. 17. Average monthly values of water transparency in the investigated shallow lakes.

weather with light wind water, as a rule, is transparent. During strong storms transparency decreased to 10 cm. Phytoplankton due to low biomass did not exert any influence on this indicator, except in cases where biomass of phytoplankton exceeded 5 mg/l.

According to Altai Department FSUE "Gosrybcenter", water transparency of deep lake Bolshoye Yarovoye ranged from 60 to 410 cm and in average for season it was 80–150 cm.

Average values per season (2002) of water transparency in shallow lakes and lake Bolshoye Yarovoye were presented in Fig. 14*B*.

2.4. Hydrobiological characteristics of lakes

The results of hydrobiological field studies and laboratory experiments, conducted from 1995 to 2004, in salt lakes of Kurgan, Omsk, Chelyabinsk, Tyumen regions, in Republics of Khakasia, Tuva and Altai territory were the material for this study.

Comprehensive survey of the lakes, including the study of abiotic (temperature, oxygen, ion composition and transparency) and biotic (phytoplankton, zooplankton and benthos) factors was conducted on the most lakes with frequency from 1 to 3 times per year. On some lakes of the region year-round or seasonal monitorings of status of Artemia populations were conducted.

Samples of zooplankton and benthos, as a rule, were collected during spring, summer and summer-autumn crustacean generations. In model lakes (Bolshoye and Maloye Medvezhye, Vishnyakovskoye, Nevidim, Ebeyty) year-round monitoring was conducted in the period from May 2000 to December 2003, with sampling frequency 1–2 times per month. In the period from 2000 to 2004 on the lakes: Bolshoye Kureynoye, Filatovo, Novo-Georgievskoye, Aktoban, Ulzhay, including model lakes in 2004, seasonal monitoring with sampling frequency 1–2 times per month during the season was conducted.

Collection and processing of samples were performed according to standard methods (Kiselev, 1956).

Sampling of zooplankton was conducted with planktonic Apshtein's network (mesh size 140 mk) in volume of 50 l or pulling from the bottom to the surface (in deep lakes) from 3–12 stations depending on the area. Samples were fixed by 4 % formalin solution. During cameral processing crustaceans were calculated in Bogorov's chamber under binocular microscope MBS-10, separated them into age groups: cysts, nauplii, juveniles, preadults, adult individuals (males, females with cysts or without cysts). The number of cysts and nauplii was counted in 5–10 ml of sample in 2–3 replications with subsequent recalculation of total volume of the sample. All adults in the sample were counted with help of Petri's plate. Individual weights of adult amphipods were determined by direct weighing on torsion balance WT-500. Data about individual weight of nauplii were taken from sources of literature (Khmeleva, 1968). The average mass of cysts, previously cleaned and dried in thermostat at temperature of 35 °C to air-dry weight, was determined by weighing on analytical balance Ohaus E2140.

Sampling of benthic samples was performed with help of benthos catch equipment with the shooting area of the ground 0.001 m^2. For washing samples from soil a bag which is made of nylon sieve (mesh size 160 mk) was used. Large organisms were counted and weighed throughout the sample. At cameral processing the volume of the sample was brought up to 200–500 ml (depending on number of samples). Number of cysts was counted in 2–10 ml in triplicate samples in Bogorov's chamber under binocular microscope MBS-10.

Season for Artemia was between mid April and mid October (180 days), for planktonic and benthic cysts the period was from June (the beginning of laying cysts by crustaceans) till November. Mean seasonal values for monitoring studies were determined as average weight value over the entire season. For populations where the samples were taken less frequently (1–4 times per season), the data were resulted in mean seasonal by multiplying fact parameter from average and index of variation. These coefficients of variation were determined by monitoring studies over five-year period (2000–2004).

Samples of phytoplankton with volume 1.5–2.0 l were concentrated by method of settling to 10 ml. Collection and processing of samples were performed according to standard techniques using a microscope Micmed-2 in Goriaev's and Fuks-Rosenthal's cells (Kiselev, 1956, 1969; Lavrenteva, Bul'on, 1981; Sorgeloos et al., 1986). To determin phytoplankton biomass individual volumes of cells were used, they were calculated taking into account the geometric shape and size according to the method proposed by I.A. Kiselev (1956). The specific weight of algae was assumed equal to 1.

2.4.1. Phytoplankton

2.4.1.1. Floristic and structural composition

The species composition of phytoplankton in salt lakes is extremely poor. For the whole period of studies in composition of phytoplankton in the lakes 58 species and varieties belonging to 6 divisions of algae were identified (App. 7, 8). Green and diatoms algae were the most diverse (22 and 20 taxons, respectively). Blue-green algae were in the third place on diversity (12 taxons). Dinophytes, cryptophytes and yellow-green algae were the least of all (1–2 taxons).

Phytoplankton environmentally is mainly presented by brackish complex of widespread, truly and facultative planktonic species belonging to β-mesosaprobic organisms.

Plankton of each lake was characterized by a certain complex of algae and counted in total for the season (App. 9) from 1 to 15 species (average 6.06 ± 0.31; $C_v = 41.7\%$; $n = 64$). Shannon's index of species diversity was low and ranged from 0.11 to 2.7 bit/mg.

The similarity of algal flora in general was low for all lakes (35.7 %) but it had a large variation in pairwise comparison of lakes (18–96 %; average 52.4 ± 0.4; $n = 325$), which is typical for freshwater algal flora of lakes (Ecological System of Naroch lakes, 1985). Species compositions of the lakes Lavrushino and Octyabrskoye were isolated relatively (average Serensen's coefficient was less than 0.4). The greatest similarity in species composition was observed in the lakes Sobachye, Vishnyakovskoye, Aktoban and Voskresenskoye (average value of Serensen's coefficient was more than 0.6).

The most part of species was found only in 1–2 lakes (62 % of total list) or 3–4 lakes (7 %). Only 4 species (*Amphora coffeaeformis*, *Nitzschia angustata*, *Dunaliella salina*, *Dunaliella viridis*) were met in all lakes with few exceptions (see App. 7).

According to own data large cluster of lakes having similar species composition was allocated by method of cluster analysis (see App. 7). At a distance of unification, equal to 3.0, this cluster was comprised of 15 lakes (App. 10). The most similar species composition was noted for lakes Bolshoye and Maloye Medvezhye (distance of unification is 1.0). At distance of unification from 3.0 to 3.5 the lakes Siverga, Trebushinoye, Solenoye 18, Oktyabrskoye, Ebeyty, Bolshoye Kureynoye were joined to large cluster. The most isolated species compositions were recorded in the lakes Nevidim, Sulfatnoye and Ulzhay.

Phytoplankton of the lakes of Kulunda steppe (Altai territory) was differed by some originality. Similaritiy with Ishim steppe lakes was observed because of poverty in species composition. In the most lakes the number of phytoplankton species did not exceed 10. A special case is the largest lake of the region — Kulundinskoye, in which the species composition of algae consisted of 36 species. Such abundance of species is due to contamination of algae in the lake by drain of the rivers Kulunda and Suetka (Solovov, Studenikina, 1990; Golubyh et al., 2000; Solovov et al., 2001; Vesnina, 2002; Yasyuchenya, 2002).

The species composition of the lakes Ishim and Kulunda steppe was quite varied. Around the list of algae only 13 species were total and similarity factor did not exceed 23 %. Ordinary for the lakes of Ishim steppe species such as *Dunaliella salina* and *Dunaliella viridis* were not marked in salt lakes of Kulunda steppe.

In quantitative terms in phytoplankton of all lakes, as a rule, green algae dominated, diatoms and blue-green had second and third places, respectively (Fig. 18, 19).

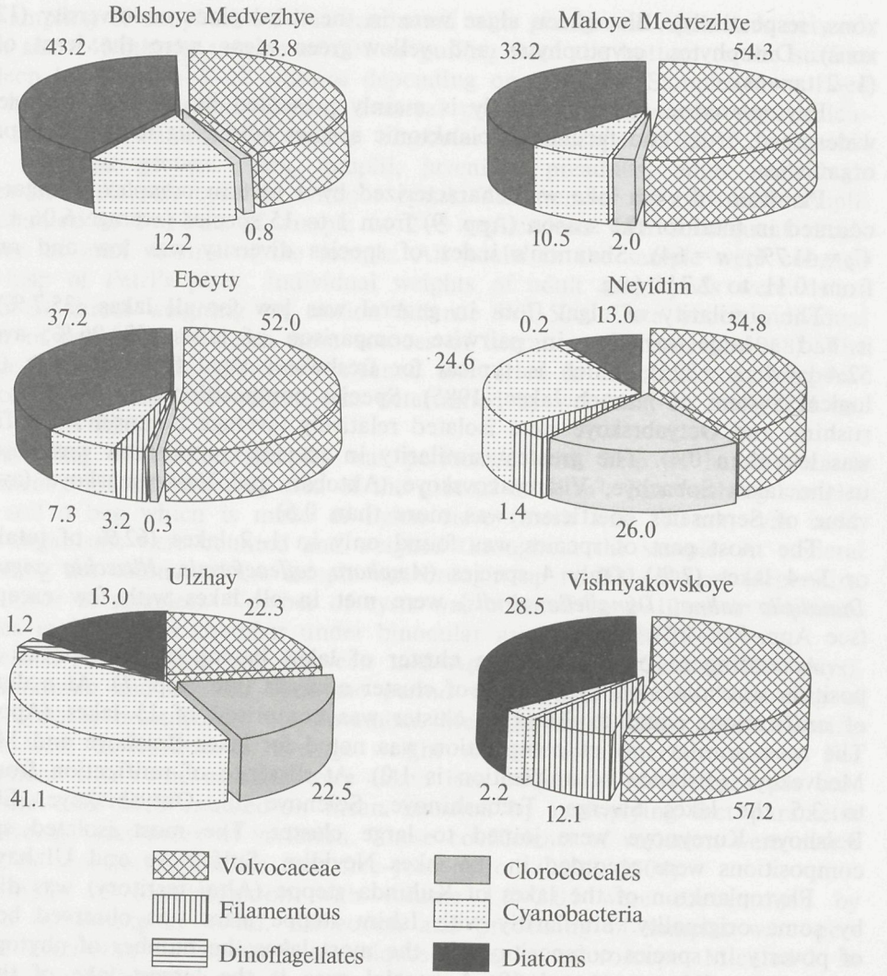


Fig. 18. Share of different groups of algae in the general biomass of phytoplankton (on the long-term data in the vegetative period), %.

For the whole period of studies in phytoplankton of the lakes during growing season green volvoks algae from genus *Dunaliella* were dominated by biomass. Diatom algae *Nitzshia angustata* and *Amphora coffeaeformis*, as a rule, were accompanied to dominants. Green algae: *Schroederia setigera*, *Ankyra judayi*, *Chlamidomonas Reinhardii*, *Korschikoviella gracilipes*, *Spermatozopsis exsultans*, *Cladophora globulina*, blue-green — *Oscillatoria limosa*, diatom — *Amphora coffeaeformis*, *Nitzschia angustata* were among the dominants rarely. The remaining species were found rearely.

In phytoplankton of lake Kulundinskoye filamentous green algae (*Cladophora glomerata*) and blue-green algae (*Lyngbya martensiana*, *Lyngbya aestuarii*, *Lyngbya*

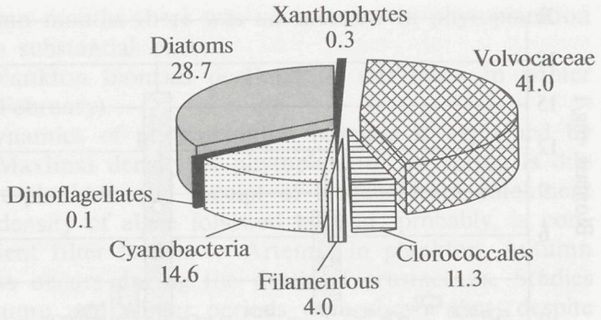


Fig. 19. Share of different groups of algae in biomass of phytoplankton for all modeling lakes (on long-term data in vegetative period), %.

lutea) were dominated in quantitative terms (Solovov, Studenikina, 1990; Vesnina, 2002).

In phytoplankton of lake Bolshoye Yarovoye in different years in spring one species of blue-green algae (*Lyngbya lutea*, *Lyngbya limnetica* and *Microcystis* sp.) was dominated; after that green algae *Chlorococcum* sp. changed them (Golubyh et al., 2000; Solovov et al., 2001; Yasuchenya, 2002).

2.4.1.2. Size structure

The length of cells of green algae was 6–16 μm, diatomaceous algae — 10–45 μm, the length of trichomes of blue-green algae is 25–88 μm. Thus, all observed species mainly belong to nannoplankton, i.e. they have a size of cells in the range 5–50 μm. It is known (Sorgeloos et al., 1986), for Artemia nutrition since nauplial stages, it is necessary to have feed, which size does not exceed 50 μm. Therefore, phytoplankton of lakes due to size composition is available for the consumption of Artemia all developmental stages. Also phytoplankton is highly estimated on composition of species, because the most encountered species (diatomaceous and green) are the best food for brine shrimps (Dobbeleir et al., 1980; D'Agostino, 1980).

The average volume of cells in lake phytoplankton communities (see App. 9) was in the range from 40 to 1256 μm^3 and in average was 225.0 ± 1.7 ($n = 75$; $C_v = 84$ %). The sizes of cells *Cladophora globulina*, which volume on average was 64 214 μm^3, were not undertaken in calculation.

2.4.1.3. Dynamics of quantitative development of phytoplankton

For the period of studies observed biomass of phytoplankton in lakes was in the range from 0.003 to 13.23 mg/l (see App. 9). Only in one case at vegetation of green filamentous algae *Cladophora globulina* phytoplankton biomass in lake Siverga reached 116.7 mg/l in June 1995.

Mean seasonal values of phytoplankton biomass were in the range from 0.01 to 11.38 mg/l, the number of cells was from 0.02 to 32.29 million cells/l. The average values of phytoplankton biomass, demonstrating its low level of development, are shown in Fig. 20. In general, during growing season biomass of phytoplankton rarely exceeded 1.0 mg/l; that is why these lakes can be attributed to oligotrophic reservoirs. Only a few lakes were an exception which on the scale of eutrophication (Trifonova, 1979; Kitaev, 1984) can be classified as mesotrophic (Novo-Georgievskoye, Nevidim and Ulzhay) and even eutrophic

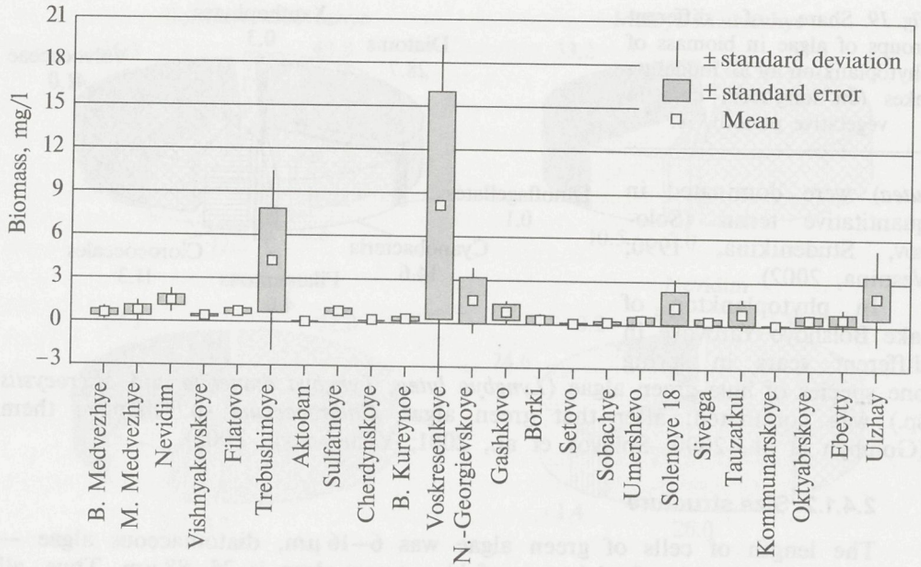


Fig. 20. Average seasonal values of biomass of phytoplankton in the investigated lakes for some years.

(Trebushinoye and Voskresenskoye) reservoirs. However, according to Fig. 20, the values of phytoplankton biomass in these lakes are very unstable and may vary significantly in different years.

Deep-water lake Bolshoye Yarovoye by level of quantitative development of microalgae is refered to oligotrophic reservoirs. According to data of Altai Department FSUE "Gosrybcenter", the density of phytoplankton in lake did not exceed 5.5 million cells/l, the average for the season biomass was small and it was approximately 0.02 mg/l. The only exception is 1999, when the number of phytoplankton increased to 22 million cells/l in June and up to 425 million cells/l in September (Golubyh et al., 2000). Unfortunately, in this work the data on phytoplankton biomass are not given. If dominant small-cell species *Microcystis* sp. is judged, the biomass of algae in 1999 did not exceed typical level for mesotrophic reservoir.

Quantitative development of phytoplankton in lake Kulundinskoye (Vesnina, 2002), namely, the number (in the range 0.3–5.01 million cells/l, average 1.31) and biomass (0.29–9.59 mg/l, average 2.74) indicates about mesotrophic type of this reservoir.

In long-term dynamics of phytoplankton (App. 11) there were some trends:

— in 72 % cases phytoplankton biomass had peaks in spring (from April to May);

— in 88 % cases the biomass of phytoplankton in summer months did not rise above 1 mg/l;

— in 71 % cases in autumn months there was an increase in phytoplankton biomass from small values to substantial ones;

— in 82 % cases phytoplankton biomass declined to minimum in winter months (from December to February).

The presented annual dynamics of phytoplankton biomass is explained by influence of several factors. Maximal density of phytoplankton in spring is due to lack of consumers of phytoplankton and receipt of biogens from catchment area. Sharp decrease in the density of algae followed by that, probably, is connected with appearance efficient filter feeders — Artemia in plankton. Autumn rise in phytoplankton biomass occurs during the death of crustaceans. Studies of phytoplankton in late autumn and winter periods were shown that, despite the decrease in water temperature (to minus 10 °C — minus 15 °C), reduction in day length and the formation of ice cover (January — February), the vegetation of microalgae continued. Dominant species in winter phytoplankton of the lakes were *Dunaliella salina*, *Dunaliella viridis*, *Schroederia setigera*, *Amphora coffeaeformis* and *Lingbya limnetica*.

It was found (Teodoresco, 1906; Dzens-Lithovskiy, 1968) that in some salt lakes amplitude of annual temperatures has an enormous scope (from –21.5 °C in winter to 75 °C in summer). Year-round algae vegetation in these reservoirs is likely associated with exceptional temperature tolerance of dominant plankton species of genus *Dunaliella*: from –30 °C (Masyuk, 1973) to 45 °C for *Dunaliella salina* (Yurkova, 1965) and 50 °C for *Dunaliella viridis* (Baas-Becking, 1930).

The analysis of algae number and biomass at different stations was shown that spatial distribution of phytoplankton in lakescape was uneven. Biomass and abundance of algae at different stations for the same date were usually differed in 2–6 times from mid-lake values. The coefficient of variation (C_v) ranged from 16 to 169 and in average it was equal to 72 %, which corresponds to high level of variability of planktonic algae density in lakescape.

2.4.1.4. Primary production of phytoplankton

Physiological activity of phytoplankton is served as a criterion intensity of selection and absorption of oxygen by algae or, other words, the intensity of photosynthesis and respiration.

The study of photosynthesis activity of phytoplankton and destruction of organic matter was performed by exposure of oxygen bottles in lake during the day (Vinberg, 1960; Buljon, 1983). *P/B*-ratios of phytoplankton are calculated on assumption that efficient production is 80% of the gross, oxycaloric coefficient is equal to 3.38 cal/mg O_2 (Vinberg, 1970; Bul'on, 1983), calorific value ranges from 0.6 to 1.0 cal/mg depending on phytoplankton species composition. The lowest amount of calorie content (0.6 cal/mg of raw material) was used in calculations if biomass of diatom algae was 100 % of total. The highest calorie content (1 cal/mg of wet material) was taken at specific weight of diatomaceous algae less than 40 %. At 85, 70, 55 % of diatomaceous content from total biomass calorie content was taken accordingly 0.7, 0.8 and 0.9 cal/mg of wet material (Mikheeva, 1970; Tereshenkova, 1983). Calculations were also used by

following transition rates: 3.33 mgO_2/mgC; 2.15 mgOS/mgC (OS — organic substance); 0.3 mgC/mgO_2; 0.65 $mgOS/mgO_2$ (Bul'on, 1983).

During the period of researches the value of daily gross photosynthesis ranged from 0.01 to 4.40 mgO_2/l (Tab. 7). Maximal values were observed, as a rule, in July — August, minimal indexes were at low biomass and abundance of algae in May — June and September. However, between phytoplankton biomass and size of daily photosynthesis relationship was very weak ($r = 0.12$).

Table 7. **Biomass of phytoplankton (*B*, mg/l), average volume of algae cells (*V*, μm³), phytoplankton production (*A*, $mgO^2/l \cdot$ twenty four hours), destruction of plankton (*R*, $mgO^2/l \cdot$ twenty four hours), the daily *A/B*- and *P/B*-coefficient in the investigated reservoirs**

Date	N the place of sampling	*B*	*V*	*A*	*R*	*A/R*	*A/B*	*P/B*	Σ_i
1	2	3	4	5	6	7	8	9	10
				Bolshoye Medvezhye					
23.05.2000	1	3.82	225	0.71	2.07	0.34	0.19	0.50	196
	3	16.58	443	0.58	0.33	1.76	0.03	0.09	196
23.06.2000	1	0.22	335	0.01	0.3	0.03	0.05	0.14	237
06.07.2000	1	0.68	197	2.80	1.84	1.52	4.12	11.15	243
	2	0.53	246	2.04	0.72	2.83	3.84	10.39	243
21.07.2000	1	0.36	175	0.90	0.80	1.13	2.47	6.69	225
	2	0.75	172	2.60	1.10	2.36	3.48	9.40	225
10.08.2000	1	0.11	225	0.31	1.10	0.28	2.74	9.27	199
	2	0.03	175	0.06	1.02	0.06	1.82	5.46	199
05.09.2000	1	0.15	182	0.28	0.17	1.65	1.92	5.19	231
	2	0.22	213	1.81	0.90	2.01	8.38	22.66	231
21.09.2000	1	0.58	617	0.16	1.92	0.08	0.28	0.75	245
	2	0.27	223	0.08	2.21	0.04	0.30	0.80	245
04.08.2001	1	0.28	118	1.00	2.50	0.40	3.55	11.99	220
	2	0.10	68	0.30	2.30	0.13	2.94	9.94	220
23.08.2001	1	0.03	78	0.14	2.24	0.64	5.33	14.42	230
				Maloye Medvezhye					
23.05.2000	4	9.46	230	1.45	1.40	1.04	0.15	0.41	169
	5	11.98	319	1.24	1.24	1.00	0.10	0.28	169
06.07.2000	4	0.88	249	0.32	2.88	0.11	0.36	0.99	246
	5	1.25	341	3.60	2.40	1.50	2.89	7.82	246
21.07.2000	4	0.87	189	2.50	1.60	1.56	2.88	7.80	225
	5	0.59	209	3.01	1.11	2.71	5.12	13.84	225
10.08.2000	4	0.55	265	3.21	2.01	1.60	5.79	15.67	215
	5	0.50	295	2.50	1.50	1.67	4.96	13.41	215
05.09.2000	4	0.13	209	0.33	1.64	0.20	2.54	6.86	255
	5	0.31	368	1.04	1.71	0.61	3.31	8.96	255
21.09.2000	4	0.24	304	0.24	1.60	0.15	1.01	2.73	247
	5	0.56	439	0.26	1.43	0.18	0.47	1.26	247
21.06.2001	5	0.09	94	1.12	1.92	0.58	2.58	7.81	197
11.07.2001	4	0.03	98	0.10	2.60	0.04	2.94	7.95	199
	5	0.05	74	0.01	1.00	0.01	0.20	0.53	199
04.08.2001	4	0.02	41	0.08	1.40	0.57	4.71	12.72	210
	5	0.06	94	0.14	4.3	0.03	2.37	6.42	210
23.08.2001	4	0.01	333	0.01	0.56	0.02	1.11	5.01	236

Table 7 (continued)

1	2	3	4	5	6	7	8	9	10
				Vishnyakovskoye					
02.06.2001	1	0.57	440	0.7	0.3	2.33	1.23	3.33	86
30.06.2001	1	0.17	268	0.38	1.3	0.29	2.22	6.01	125
25.07.2001	1	0.09	119	1.6	1.1	1.45	17.39	4.70	122
				Nevidim					
28.06.2001	2	2.81	193	2.0	4.08	0.49	0.71	1.93	95
	3	2.81	193	0.48	0.8	0.60	0.17	0.46	95
02.08.2001	2	4.33	169	1.3	2.5	0.52	0.30	0.81	108
	3	4.33	169	4.4	3.6	1.22	1.02	2.75	108
				Ebeyty					
20.05.2001	1	0.08	101	0.4	0.43	0.93	4.94	13.35	210
15.06.2001	1	0.16	81	1.28	2.48	0.52	7.95	21.50	285
M		1.61	226	1.10	1.64	0.87	2.82	6.82	204
min		0.01	41	0.01	0.17	0.01	0.03	0.09	86
max		16.58	617	4.40	4.30	2.83	17.39	22.66	285
σ		3.40	120	1.15	0.96	0.82	3.15	5.87	50
C_v, %		211	53	104	59	94	112	86	25

It is known (Mikheeva, 1983) that temperature optimum of most algae is within 15–20 °C, only for blue-green algae it is higher and between 20 and 30 °C. The temperature optimum for the most common species of phytoplankton community of salt lakes *Dunaliella salina* and *Dunaliella viridis* is within 20–32 °C (Yurkova, 1965) and 14–30 °C (Gibor, 1956), respectively. Photosynthetic temperature optimum for species of genus *Dunaliella* is slightly higher and close to 35 °C (Wegmann, 1968). This is probably due to that photosynthetic activity in mid-summer at the warmest water was maximum even at low phytoplankton biomass.

Minimal values of photosynthesis were observed during strong heating of water in June 2000 (see Tab. 7). It assisted decline of content of dissolved oxygen in lake Bolshoye Medvezhye almost to 0 and mass death of Artemia crustaceans.

According to average values of primary production and scale of eutrophication (Vinberg, 1960; Bul'on, 1983; Kitaev, 1984), studied salt lakes can be attributed to mesotrophic lakes.

Value of primary production in general during growing season (from April to October) was in the range from 18 mgC/l (Maloye Medvezhye, 2001) to 112 mgC/l (Nevidim, 2001) and in average for studied lakes it was 55.1 ± 12.9 mgC/l ($\sigma = 34.3$; $C_v = 62$ %; $n = 7$). Due to these indexes investigated lakes were also characterized as mesotrophic lakes (Fig. 21).

Destruction of organic substance, equivalent associated with breathing of whole plankton community in lake varied from 0.17 to 4.30 mgO_2/l (see Tab. 7). In seasonal dynamics of this indicator there were no any patterns. We can only say that with decrease of photosynthesis intensity in late September the level of destruction of organic substance remained the same and even increased slightly.

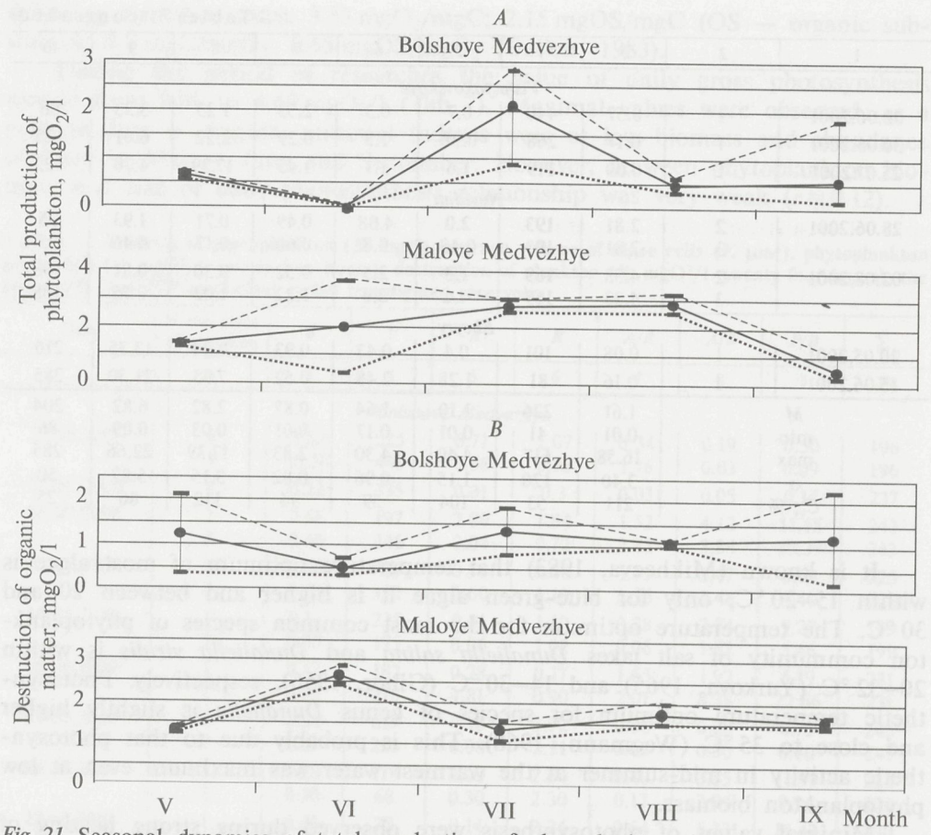


Fig. 21. Seasonal dynamics of total production of phytoplankton (*A*) and destruction of organic matter (*B*) in Bolshoye and Maloye Medvezhye Lakes (2000 year).

The indicator of efficiency of productive processes, expressed by the ratio of primary production and destruction of organic substances (*A/R*) was in the range from 0.01 to 2.83 (see Tab. 7) and in average it was less than 1. It is typical for reservoirs where the proportion of bacteria and their production are comparable to production of phytoplankton (Bul'on, 1983).

The analysis of phytoplankton functioning on the value of specific photosynthesis (*A/B*) has shown that algae-cenoses of investigated salt lakes due to their micro-cells structure, certain species composition (especially, availability of volvocales) and also probably because of some physiological characteristics are very productive. So, daily values *A/B*-coefficients of phytoplankton in the lakes were in the range 0.03–17.39 and on average they were equal to 2.82 day^{-1}. *P/B*-coefficients of phytoplankton in studied lakes ranged from 0.09 to 22.66 and on average 6.82 day^{-1}.

At maximal values of *P/B*-ratios in plankton nannoplankton forms of volvocales and blue-green algae dominated. The turnover ratio of biomass (reciprocal *P/B*-ratio) for algaecenoses in salt lakes was on average 0.15 days. Such high turnover rate of phytoplankton biomass was also observed in some freshwater reservoirs (Czeczuga, 1960; Jonasson, Kristiansen, 1967), as well as in laboratory studies during cultivation of some micro diatoms (Jorgensen, 1966). Higher specific daily production (11.4–15.6) was marked for flagellate *Chlamydomonas* sp. (Gutelmacher, 1973, 1974).

The analysis of coefficients of pair correlation of indexes phytoplankton function was noted presence of weak positive relationship between salinity and specific photosynthesis ($r = 0.30$). In addition, our experiments were revealed that between specific photosynthetic activity of algae and cell volume of phytoplankton community there is an inverse relationship ($r = -0.40$). It confirms once more the fact that small-cell communities are the most productive.

Phytoplankton due to relatively low values of biomass, probably did not affect significantly the change in transparency. This is evidenced by the lack of closed correlation between these values (*r* from 0.02 to 0.15) for model lakes Bolshoye and Maloye Medvezhye, Nevidim and Vishnyakovskoye.

Thus, phytoplankton of salt lakes is poor by species composition, ecologically it is represented by halophilous and mesohalobiont organisms, as for dimensional composition it refers to nannoplankton, in quantitative term it has a low density, in physiological term it is highly productive.

2.4.2. Zooplankton

During research period 13 species belonging to two types (in systematic relation): arthropods (Arthropoda) and round worms (Nemathelminthes) were found in plankton of salt lakes. There were 6 representatives of crustaceans (Branhiopoda — 2, Copepoda — 3, Cladocera — 1), three species of larvae insects, three species of rotifers and one species of nematode (App. 12).

All noted species belong to either halobionts or halophils (*Artemia*, *Cletocamptus retrogressus*, *Brachionus plicatilis*, larvae *Ephydra*), or species with wide ecological valence; they were found both in fresh and salt waters. With increasing water salinity number of species decreased significantly (Fig. 22), the role of *Artemia* in community increased and share of other species in total biomass decreased (Fig. 23, 24). Probably, salinity above 70–80 g/l is a barrier to development of all related species. However, rearely these species were found at higher salinity. Such species as crustacean *Moina microphthalma*, rotifers *Brachionus plicatilis* and *Epiphanes* sp. were not found with salinity higher than 149 g/l. Occurrence of copepod crustacean *Cletocamptus retrogressus* in lakes was limited by salinity 198 g/l, larvae of Chironomidae — 213 g/l, larvae of flies (family Ephydridae) — 255 g/l. Large crustacean *Branchinectella media*, presumably, being a predator, was not found with salinity above 67 g/l and was registered in one lake (Siverga) in 1995, in 6 lakes (Siverga, Filatovo, Trebushinoye, Aktoban, Voskresenskoye, Tauzatkul) in 2002 and in two lakes (Trebushinoye and Aktoban) in 2003. In dry years its area was significantly decreased, in wet years, on the contrary, it was increased. In saline lakes (Ebeyty, Bolshoye and Maloye Medvezhye, Bolshoye Yarovoye, Malinovoye) in

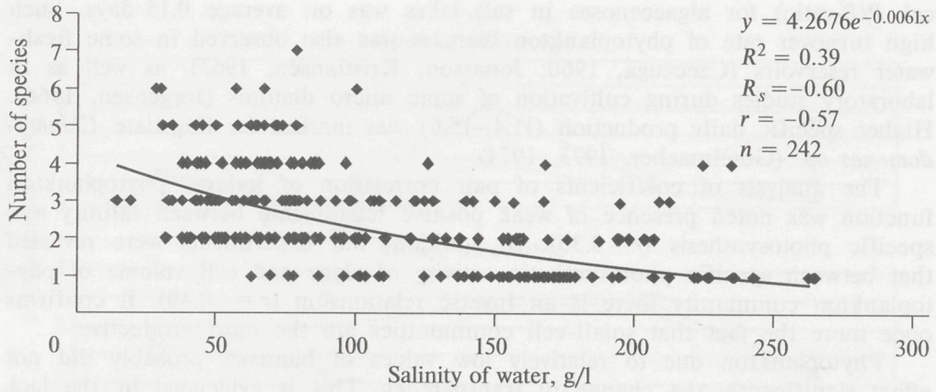


Fig. 22. Dependence of zooplankton species number from salinity of water in the investigated lakes for the period from 1995 to 2004 (on the average data for the year).

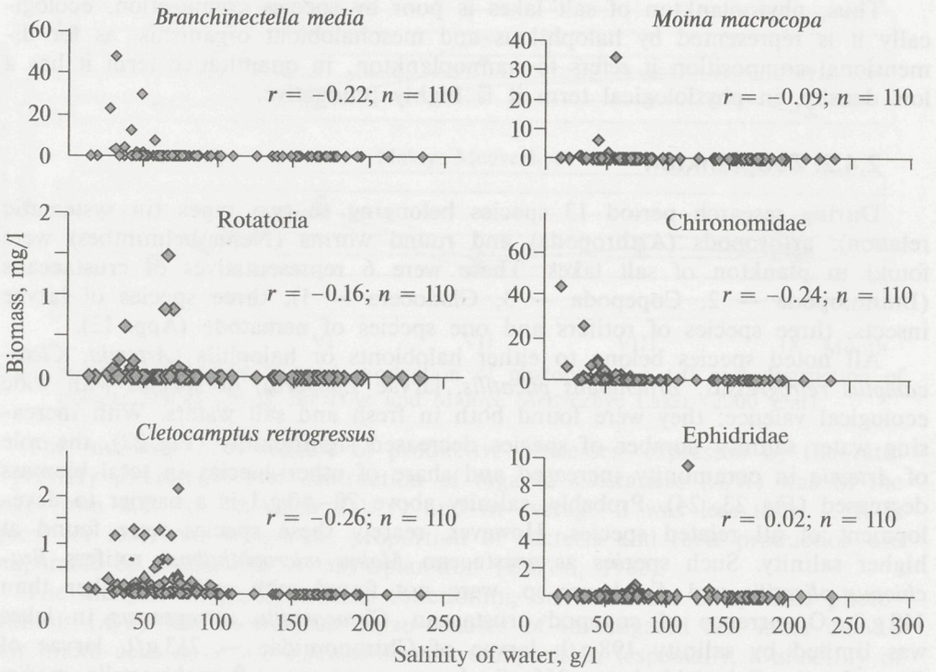


Fig. 23. Biomass of zooplankton (without Artemia) in lakes with different salinity (as of 1995–2004).

plankton there was an only halobiont from the genus *Artemia*. Other species were so rare that it could be considered that Artemia in these lakes were grown in monoculture. Maximum salinity observed for brine shrimp was equal to 299 g/l.

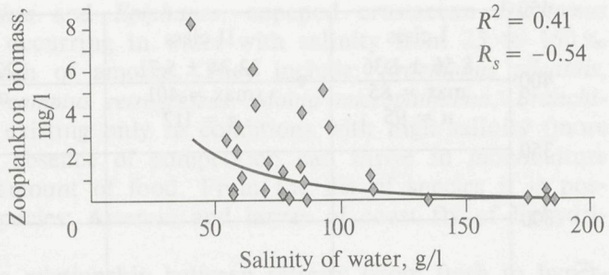


Fig. 24. Ratio between biomass of zooplankton (without Artemia) and salinity of water (on average long-term data).

Correlation analysis between biomass of individual species of zooplankton and salinity of environment has shown a significant negative relation for *Branchinectella media*, *Moina microphthalma*, *Cletocamptus retrogressus*, larvae Chironomidae and rotifers and the lack of reliable communications for larvae Ephydridae. Artemia biomass and number of cysts responded positively to increasing salinity up to 250 g/l (Tab. 8).

Taking into account total salinity of the lakes and status of *Artemia* population all studied lakes were divided into 4 classes (Litvinenko et al., 2002, 2004).

Analysis of Artemia quantitative development for whole period of studies have shown that in lakes of conditionally allocated class I ($\Sigma_i < 70$ g/l, on average for all lakes $\Sigma_i = 51.4 \pm 1.5$ g/l) populations of brine shrimps are in depressed state due to the large amount of food competitors, occurrence of them was 100%. Maximum Artemia biomass in these lakes did not rise above 85 g/m^3. Average biomass for all lakes of this group was equal 8.56 ± 1.36 g/m^3 (Fig. 25).

In lakes of class II ($\Sigma_i = 71$–150 g/l, on average for all lakes $\Sigma_i = 100.1 \pm 2.0$ g/l) record values of maximal crustacean biomass (401 g/l in lake Soleniy Kulat) were noted. The average indexes of Artemia biomass in all lakes of this group were equal 32.74 ± 5.71 g/m^3. The incidence of food competitors of Artemia (mainly *Cletocamptus retrogressus*, less Chironomidae larvae and rotifers) in this group of lakes was in the range 65–75 %.

In lakes of class III ($\Sigma_i = 151$–250 g/l, on average for all lakes $\Sigma_i = 193.4 \pm 2.9$ g/l) Artemia grow in monoculture. Maximal shrimp biomass did not exceed 202 g/m^3. Average Artemia biomass was 22.15 ± 4.23 g/m^3.

Table 8. **Spearmen coefficients of correlation between salinity and biomass of different species zooplankton**

Name of the zooplankton taxa	Sampling volume	R_s	$t(n-2)$	p
Branchinectella media	255	−0.32	−5.42	1.39E−07
Moina macrocopa	252	−0.36	−6.00	6.81E−09
Rotatoria	253	−0.38	−6.42	6.66E−10
Cletocamptus retrogressus	290	−0.56	−11.59	9.34E−26
Larvas Chironomidae	298	−0.54	−10.90	1.77E−23
Larvas Ephydridae	274	−0.11	−1.79	0.075264*
Artemia	297	0.16	2.69	0.007584
Cysts of Artemia	305	0.49	9.79	7.74E−20

Note. * Correlation is not significant at 0.05 level.

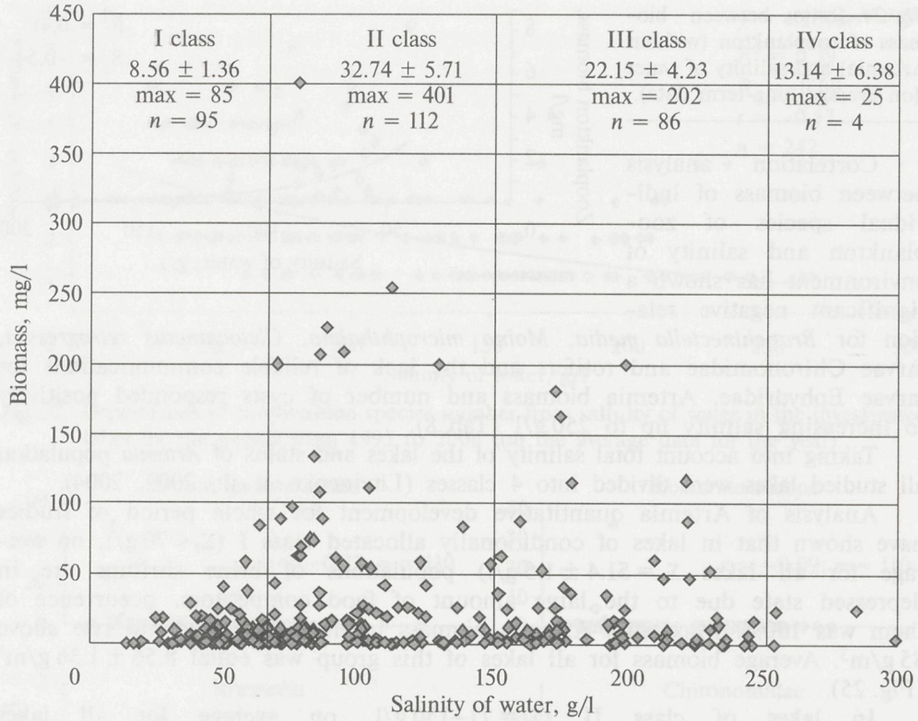


Fig. 25. Biomass of Artemia in lakes with different salinity of water.

The lakes Ebeyty (2001), Maloye and Bolshoye Medvezhye (2000) were assigned to class IV. Maximum Artemia biomass in this period did not exceed 25 g/m^3. The average index of shrimp biomass was 13.14 ± 6.38 g/m^3. Lake Ebeyty still belonged to class IV in 2001, in 2002–2004 this lake desalinated and moved into more productive class III. After that in 2002 this values of maximal and average Artemia biomass increased, respectively, in 1.9 and 1.7 times; in 2003 they became higher in 2.8 and 1.1 times, but in 2004 they decreased in both biomass in 1.5 times.

Comparative analysis of Artemia productivity in different classes of salinity has shown that there were significant differences ($p < 0.05$) between I and II class and between I and III, the difference between the rest of samples (I–IV, II–III, III–IV, II–IV) is unreliable.

Hyperhaline reservoirs, which include, according to international classification (Beadle, 1969), lakes with salinity higher 40 ‰, are inhabited by organisms with different degree of adaptation to salinity. Among them there are 3 groups of organisms: haloxena, halophila and halobiontic. Haloxena, by chance getting into salt water and surviving in it, as a rule, do not give a high number in these conditions. Normal salinity at which they can meet is 25–30 ‰, the maximum salinity — 100 ‰ (Gusev, 1990). From our list it is possible to take

rotifers from genus *Hexarthra* and *Epiphanes*, copepod crustacean *Diaptomus cyaneus*. Halophila, mainly occurring in water with salinity from 25 to 150 ‰ (Gusev, 1990), can give flash of amount. They include: *Brachionus plicatilis*, *Arctodiaptomus salinus*, *Cletocamptus retrogressus*, *Moina microphthalma*, *Branchinectella media*. Halobiontic, existing only in conditions with high salinity (more than 150 ‰), as a rule, in absence of competition can thrive in monoculture when they have sufficient amount of food. From the list of species it is possible to include only two species: Artemia and larvae of coast fly of Ephydridae family.

The existence of inverse relationship between salinity (from fresh to hypersaline) and species diversity of zooplankton is well known fact in science (Carpelan, 1957; Hussainy, 1969; Ivanova, 1990; Vesnina, 2002). In our researches at low salinity (till 70 ‰) 5 or less species existed together with Artemia; if salinity ranged from 70 to 150 ‰ their number reduced to 3. When salinity was above 150 ‰ there was only one species in plankton fauna — the genus *Artemia*, another halobiont — *Ephydra* sp. habited in littoral.

According to our data, salinity boundary of Cladocera distribution is in the level 150 g/l (130 ‰), Copepoda and Chironomidae larvae — 200 g/l (167 ‰), Ephydridae larvae — 250 g/l (200 ‰), *Anostraca* — 300 g/l (230 ‰). Our researches have been allowed to expand ideas about the boundaries of occurrence for some groups of zooplankton. So, for representatives of Cladocera this boundary did not exceed 50–110 ‰, Copepoda — 90–110 ‰ (Moore, 1952; Hammer et al., 1975; Ivanova, 1990; Ramdani et al., 2001).

Thus, zooplankton of Artemia lakes is very poor, the number of species is inversely dependent on water salinity. At salinity more than 150 ‰ fauna of lake pelagic zone is represented by one species of the genus *Artemia*. Some species of zooplankton can meet singly at higher salinity.

2.4.3. Zoobenthos

Lake zoobenthos was presented by larvae of coast fly Ephydridae family, ephippiums of cladocera *Moina microphthalma* and Artemia cysts. Larvae of coast flies presented in every third sample in amount from 10 to 200 ind./m^2, but in some lakes their number reached 500–600 ind./m^2 (Solenoye 18; Gashkovo (July, 2000)). In 17 % of all lakes ephippiums *Moina microphthalma* appiered in benthos while their number was in the range from 80 to 390 ind./m^2. Bottom Artemia cysts were found in all lakes almost all-year-round, their absence was noted only in certain waters in winter and spring months. The average amount of cysts on the stations was in the range from 0 to 18.6 million ind./m^2, biomass — from 0 to 186 g/m^2. At some stations the number of benthic cysts reached 32 million ind./m^2 or 320 g/m^2.

Chapter 3

SYSTEMATIC POSITION OF SIBERIAN ARTEMIA POPULATIONS ON THE BASIS OF MORPHOLOGICAL AND GENETIC STUDIES

Previously Artemia species belonging in Western Siberia has not been investigated. Until the beginning of new millennium in publications of domestic scientists all Artemia populations were referred to the same species *Artemia salina* L., 1758 (Solovov, Studenikina, 1992; Studenikina, 1999; Solovov et al., 1999; et al.). However, numerous studies of scientists all over the world (at first — morphological investigations and experiments on crossing, later — cytological, biochemical and genetic studies) showed dissociation species of the genus *Artemia*. To full identification of Artemia species in lakes of Western Siberia we use only genus name Artemia for bisexual populations, for parthenogenetic — *Artemia parthenogenetica*.

3.1. Morphometric parameters of brine shrimps and cysts

3.1.1. Morphometry of cysts

The practical value of Artemia cysts is determined by morphometric parameters. So they are used mainly in live feed as a starter, the primary parameter for them is admission size. The smaller cysts, the smaller size of nauplii, the more available feed for larvae of cultivated aquatic organisms. Small cysts *A. persimilis* and *A. franciscana* are the most valuable in this attention. With substantial thickness of chorion (protective outer layer of cyst, impregnated with chitin and hematin) small nauplii can hatch from relatively large cysts. That is why it is important to know not only diameter of cysts, but diameter of decapsulated cysts (cysts with dissolved chorion).

The study of morphometric parameters of cysts and nauplii was held on 12 Siberian populations (App. 13).

Diameter of cysts on average in populations ranged from 241–289 microns; diameter of decapsulated cysts is 218–264 microns, thickness of chorion is 3.9–12.5 microns; the length of just hatched nauplii is 432–502 microns. According to data of literature (Vanhaecke, Sorgeloos, 1980; Sorgeloos et al., 1986) diameter of cysts from different populations is 224–320 microns; diameter of decapsulated cysts — 207–296 microns; chorion thickness — 4.7–11.2 microns; length of nauplii — 428–517 microns. Comparative analysis of

published data has shown that sizes of cysts and Artemia nauplii of Siberian populations occupy an intermediate position, except for the thickness of chorion, which values ranged from population to population in wider range.

The smallest cysts and nauplii were found in population of Ulzhay Lake, the largest — in lake Aktoban. The correlation between cyst diameter and thickness of chorion was weak ($r = 0.33$), it was strong positive ($r = 0.80$) between cyst diameter and length of just hatched nauplii.

Thus, using published data (Abotzopoulos et al., 1998, 2002), it can be concluded that Artemia populations are well separated from *A. tibetiana* with sufficiently large cysts and nauplii (up to 330 and 667 microns, respectively) and from *A. tunisiana* (*salina*), *A. persimilis*, *A. franciscana* — with small cysts (average 220–250 microns).

3.1.2. Morphometry of adult brine shrimps

Adult Artemia crustaceans from natural populations and cultured in laboratory were start material for morphometric studies. Incubation of cysts and cultivation of shrimps were performed according to the method described in "Instruction for the use Artemia in Aquaculture" (Litvinenko et al., 2000).

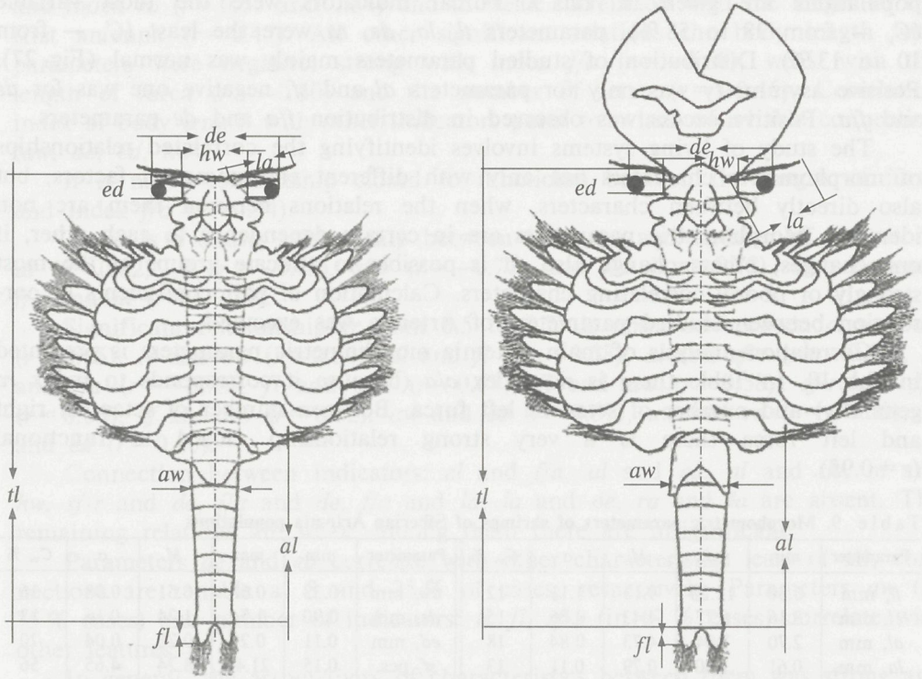


Fig. 26. Scheme of Artemia body with the indication of morphometric parameters. Symbols look in list of abbreviations (p. 8).

Before measuring shrimps were fixed in 4 % solution of formalin. Cameral processing was performed with help of microscope MBS-10 equipped with an eyepiece-micrometer.

Analysis was performed on 15 morphometric characteristics, 13 from them were plastic dimensions and two — meristic ones: *tl*, *al*, *cl*, *aw*, *de*, *ed*, *fl*, *fw*, *la*, *hw*, *ra*, *c/a*, *f/a*, *sf-r*, *sf-l* (Fig. 26, the designations were given in Ch. "List of Abbreviations").

3.1.2.1. Morphological characteristics of brine shrimps from natural populations

The investigations were carried in the lakes of Western Siberia, Khakasia and Tuva with use of 8 parameters (*tl*, *cl*, *al*, *c/a*, *fl*, *sf*, *f/a*, *fw*) from 1995 to 2002 and 11 parameters (*tl*, *al*, *aw*, *de*, *ed*, *sf*, *fl*, *la*, *hw*, *ra*, *c/a*) from 2002 to 2004 (App. 14). Annually it was surveyed from 7 to 29 populations (total 125). Only 3 populations among all studied ones were bisexual (the lake Tanatar in Altai territory and two lakes in Khakasia and Tuva). Therefore, the main part of analysis was performed only on mature females. Totally it has been measured more than 5 thousand crustaceans (at least 30 in each population).

Mean values of morphometric parameters of all studied Siberian Artemia populations are given in Tab. 9. Furcal indicators were the most variable (C_v — from 38 to 58 %), parameters *tl*, *la*, *de*, *ra* were the least (C_v — from 10 to 13 %). Distribution of studied parameters mainly was normal (Fig. 27). Positive asymmetry was only for parameters *al* and *sf*, negative one was for *de* and *f/a*. Positive excess was observed in distribution *f/a* and *de* parameters.

The study of living systems involves identifying the correlated relationships of morphometric characters not only with different environmental factors, but also directly between characters, when the relations between them are non identical. Morphometric parameters are in certain dependence to each other, if one changes, others change also. It is possible to allocate groups of the most strongly or poorly correlating characters. Calculation of pair coefficients of correlation between studied parameters of Artemia was executed.

Correlation analysis of main Artemia morphometric parameters is presented in Tab. 10. In Table there is no index *c/a* (because it corresponds to index *ra* generally) and number of setae in left furca. Between number of setae on right and left furca there is a very strong relationship closed to functional ($r = 0.95$).

Table 9. **Morphometric parameters of shrimps of Siberian Artemia populations**

Parameter	min	max	*M*	σ	C_v, %	Parameter	min	max	*M*	σ	C_v, %
tl, mm	6.30	12.28	9.13	1.11	12	*aw*, mm	0.33	0.68	0.51	0.08	16
cl, mm	3.16	6.77	4.43	0.66	15	*de*, mm	0.90	1.54	1.24	0.16	13
al, mm	2.70	7.04	4.73	0.84	18	*ed*, mm	0.11	0.29	0.20	0.04	20
la, mm	0.61	1.00	0.79	0.11	13	*sf*, pcs.	0.15	21.40	8.24	4.65	56
fl, mm	0.08	0.51	0.26	0.10	38	*f/a*, %	1.34	21.97	5.87	3.40	58
fw, mm	0.10	1.40	0.78	0.34	43	*ra*, %	35.44	64.12	51.51	5.38	10
hw, mm	0.36	1.01	0.65	0.16	25	*c/a*	0.56	1.58	0.97	0.21	21

Table 10. **Correlation matrix of morphometric parameters**

Parameter	*tl*	*cl*	*al*	*fl*	*sf-r*	*f/a*, %	*aw*	*de*	*ed*	*la*	*hw*	*ra*, %
tl	**1.00**	**0.55**	**0.91**	**−0.40**	**−0.46**	**−0.60**	0.14	0.11	0.14	**0.44**	0.15	**0.54**
cl		**1.00**	0.17	0.21	0.25	0.03	**0.65**	0.25	0.25	**0.45**	**0.54**	**−0.38**
al			**1.00**	**−0.58**	**−0.68**	**−0.73**	−0.15	0.00	0.03	0.29	−0.08	**0.82**
fl				**1.00**	**0.67**	**0.94**	**0.58**	0.14	**0.42**	0.19	0.26	**−0.73**
sf-r					**1.00**	**0.66**	**0.52**	0.06	0.28	0.18	**0.45**	**−0.77**
f/a, %						**1.00**	**0.40**	0.04	0.27	−0.01	0.15	**−0.78**
aw							**1.00**	0.30	**0.67**	**0.45**	**0.46**	**−0.55**
de								**1.00**	0.13	0.07	**−0.45**	−0.12
ed									**1.00**	**0.60**	0.12	−0.22
la										**1.00**	**0.41**	−0.01
hw											**1.00**	−0.32
ra, %												**1.00**

Note. The fat font designates significant connections at $p < 0.05$. The units of parameters are given in Tab. 9.

Between analyzed features different degree of relationship was found. The body length of shrimps is in very strong positive correlation with the length of abdomen ($r = 0.91$), in significant correlation with the length of cephalothorax and index *ra* ($r = 0.55$ and 0.54) and in weak correlation with the length of the first antenna ($r = 0.44$). All other significant relations the body length with parameters were negative: strong with index *f/a* ($r = -0.60$), weak with the length of furca ($r = -0.40$) and the number of setae ($r = -0.46$). Correlation index of body length with other indicators point to a lack of reliable connection (*aw*, *de*, *ed*, *hw*).

It is noted relationship closed to functional between the length of furca and index *f/a* ($r = 0.94$).

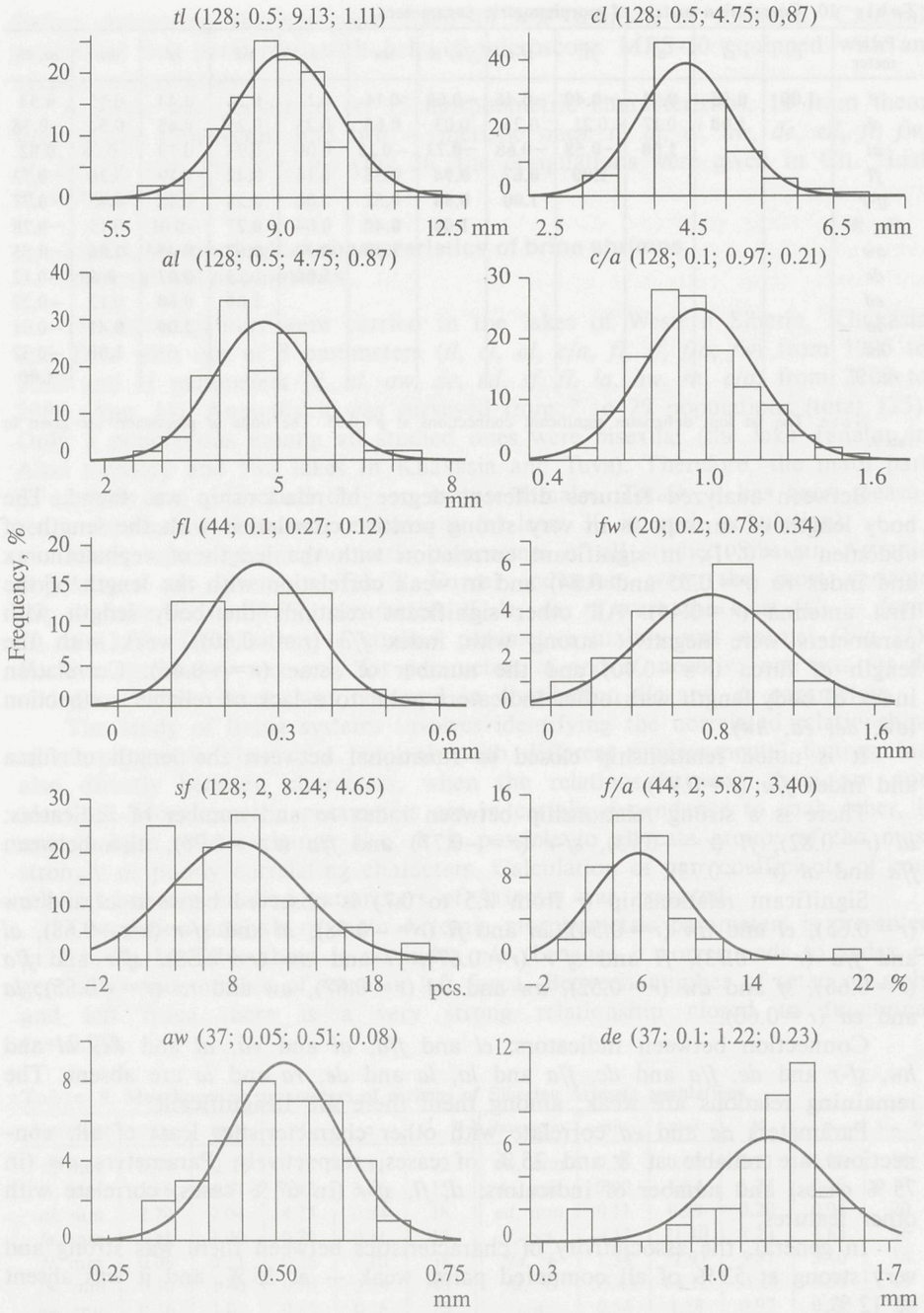
There is a strong relationship between index *ra* and number of indicators: *al* ($r = 0.82$), *fl* ($r = -0.73$), *sf-r* ($r = -0.77$) and *f/a* ($r = -0.78$), also between *f/a* and *al* ($r = -0.73$).

Significant relationship (*r* from 0.5 to 0.7) is observed between *cl* and *aw* ($r = 0.65$), *cl* and *hw* ($r = 0.54$), *al* and *fl* ($r = -0.58$), *al* and *sf-r* ($r = -0.68$), *al* and *f/a* ($r = -0.73$), *fl* and *sf-r* ($r = 0.67$), *fl* and *aw* ($r = 0.58$), *sf-r* and *f/a* ($r = 0.66$), *sf* and *aw* ($r = 0.52$), *aw* and *ed* ($r = 0.67$), *aw* and *ra* ($r = -0.55$), *la* and *ed* ($r = 0.60$).

Connection between indicators: *cl* and *f/a*, *al* and *ed*, *al* and *de*, *al* and *hw*, *sf-r* and *de*, *f/a* and *de*, *f/a* and *la*, *la* and *de*, *ra* and *la* are absent. The remaining relations are weak, among them there are insignificant.

Parameters *de* and *ed* correlate with other characteristics least of all, connections are reliable at 8 and 25 % of cases, respectively. Parameters *aw* (in 75 % cases) and number of indicators: *tl*, *fl*, *sf-r* (in 67 % cases) correlate with other features.

In general, the associativity of characteristics between them was strong and very strong at 53 % of all compared pairs, weak — at 35 %, and it was absent at 12 %.



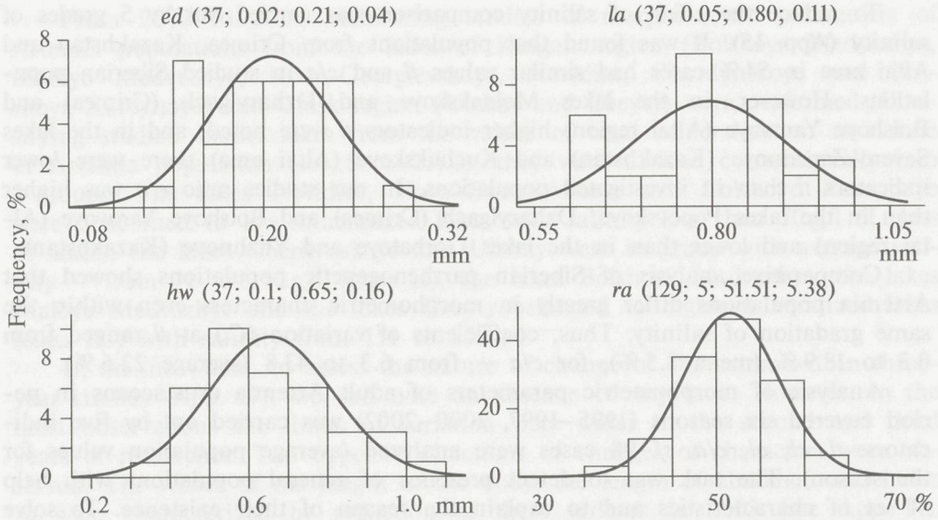


Fig. 27. Histograms of distribution of average morphometric parameters of Artemia adult female in 29 populations in several seasons.

In brackets: number of analyzed populations, step on the histogram, average, a standard deviation.

In literature there are data about evidence of positive relationship between the length of the body and the length of the first antenna, as well as the length of abdomen, abdomen width, the width of the head and furcal characteristics (Pilla, 1992). The feature of crustacean growth of studied Russian Artemia populations was the fact that the length of the body negatively correlated with the length of furca and the number of furcal setae. Moreover, the last regularity was traced in Artemia populations in different vegetation seasons.

Thus, it should be noted that correlation analysis of the main morphometric parameters of studied Artemia populations showed associations between characteristics at one level or another. Correlation coefficients ranged from 0.00 (the length of abdomen and the distance between the eyes), which means the absence of communication, till 0.95 (the number of setae on right and left furcas), which says about functional correlation.

Comparison of some indicators of Artemia growth from studied populations with data of other authors revealed the following:

— parthenogenetic Artemia populations from Yugoslavia (Majić, Vukadin, 1987) in compare with population of lake Vishnyakovskoye (salinity is about 100–120 ‰) were similar in many characteristics, except for number of setae on furca;

— parthenogenetic populations from India (Basil et al., 1987) had the length of the body of crustaceans (9.5 ± 0.5 mm) closed to values of Siberian populations;

— parthenogenetic Artemia population from Altai territory, Crimea and Kazakhstan (Voronov, 1979; Solovov, Studenikina, 1990) had similar values of the length of the body and *c/a* ratio with crustaceans of studied populations.

To reduce the effect of salinity comparison was carried out by 5 grades of salinity (App. 15). It was found that populations from Crimea, Kazakhstan and Altai area in 54 % cases had similar values *tl* and *c/a* in studied Siberian populations. However, in the lakes Mojnakskoye and Dzharylgach (Crimea) and Bolshoye Yarovoye (Altai region) higher indicators *tl* were noted, and in the lakes Severo-Zapadnoye (Kazakhstan) and Kuchukskoye (Altai area) there were lower indicators *tl* than in investigated populations. In our studies ratio *c/a* was higher than in the lakes Popovskoye, Dzharylgach (Crimea) and Bolshoye Yarovoye (Altai region) and lower than in the lakes Gorbatoye and Yuzhnoye (Kazakhstan).

Comparative analysis of Siberian parthenogenetic populations showed that Artemia populations differ greatly in morphometric characters even within the same gradation of salinity. Thus, coefficients of variation (C_v) at *tl* ranged from 0.3 to 18.9 % (mean 8.5 %), for *c/a* — from 6.3 to 43.8 (average 22.6 %).

Analysis of morphometric parameters of adult Artemia crustaceans in period covered six seasons (1995–1997, 2000–2002) was carried out by five indicators: *tl*, *cl*, *al*, *c/a*, *sf*. 98 cases were analyzed (average population values for the season). The task was to detect presence of general populations with help of set of characteristics and to explain the reason of their existence. To solve this problem the method of clustering was chosen. Unweighted pair-group method is the most widely adopted, where arithmetic mean is used. This method determines intercluster distance as average for all pairwise distances between members of two clusters (Weir, 1995). This method was applied as integrating analysis.

Cluster analysis presented in App. 16 showed rather big distance of Artemia association with another species of shrimps *Branchinectella media* (lake Siverga, 2000). The analysis of Artemia populations revealed two large clusters *A* ($n = 72$) and *B* ($n = 26$) and in each cluster there were two subclusters: A_1, A_2 and B_1, B_2. As it is known about influence of salinity on proportions of Artemia body, the average values of salinity of crustacean habitats, united in these clusters, were calculated. In cluster *A* water salinity ranged from 38 to 292 g/l, average — 129, $\sigma = 65$; in cluster *B* — from 28 to 140 g/l, average — 73, $\sigma = 30$. Between these clusters significant differences in salinity at high level of significance were noted. In subcluster A_1 average salinity was equal to 184 g/l, $\sigma = 63$; in subcluster A_2 it was 98 g/l, $\sigma = 41$. Between these subclusters significant differences in salinity at high level of significance were also revealed. Dedicated subclusters in cluster *B* differed in salinity weakly and insignificantly: B_1 — 81.0 g/l, $\sigma = 19$, B_2 — 72 g/l, $\sigma = 32$. In addition, mineralization in the lakes of cluster *B* was significantly different from subclusters A_1 and A_2.

Thus, the analysis of clusters revealed three clusters significantly differed from each other and grouped by salinity: the first group includes lakes with high salinity (A_1), the second — with average salinity (A_2), the third — with weak salinity (*B*). These data confirm the decisive influence of salinity on proportions of Artemia body. Moreover, Artemia populations in the same reservoir in different seasons were in different clusters. Also in the division of clusters there is not any influence of geographical location of lakes, although analyzed waters are at considerable distance from each other (from the Urals to Altai area).

From 2002 to 2004 monitoring studies of morphometric parameters of Artemia populations from the lakes of Kurgan region (Bolshoye Medvezhye, Maloye Medvezhye, Novo-Georgievskoye, Nevidim, Cherdynskoye and Bolshoye Kureynoye) and Omsk region (Ulzhay and Ebeyty) were performed. Classifying studied model lakes from the values of total mineralization and state of Artemia population (see Sect. 2.4.2), they were divided conventionally into 3 groups. The lakes Nevidim, Novo-Georgievskoye and Bolshoye Kureynoye were concerned to low-mineralized lakes with salinity less than 70 g/l (I class of lakes); the lakes Cherdynskoye and Ulzhay were in group with average salinity — from 71 to 150 g/l (class II), the lakes Bolshoye Medvezhye, the lakes Maloye Medvezhye and the lakes Ebeyty belonged to highly-mineralized lakes (class III) with salinity from 151 to 250 g/l.

If, on the whole, to assess the nature of change of characters within three-year studies (App. 17), we can note an absence of any laws. However, in the most observations the limits of variation were wider in the second and third years of researches. Two opposite directions of changes of characters were observed. The values of the length of the body, the length of abdomen and index *ra* were characterized by reduction of these indexes in 2003 (see App. 14). Seasonal values of other characters (the width of abdomen, the width of the head, the distance between eyes, eye diameter, number of setae and the length of furca) were, on the contrary, above for brine shrimps in 2003. Differences were statistically significant in most cases (61 %) (App. 18).

Thus, Artemia from eight monitoring lakes in season 2003 had the least elongated body, as well as the largest number of setae on furca and the longest furca.

Seasonal mean values of the length of the body and the length of abdomen in seasons 2002 and 2003 differed insignificantly. In 2004 these parameters were significantly higher. Increase in number of furcal setae and furca length was marked in 2003. The total mineralization of lakes in that season, as a whole, was lower than in 2002 and 2004. Season in 2003 was characterized by higher water availability and, hence, total mineralization of lakes was a little reduced. It was probably reflected on characteristics of brine shrimp growth.

Distribution of values of Artemia morphometric parameters from investigated lakes is presented in App. 19. Lakes in histogram were arranged according to decreasing of mineralization. For all three years of researches inverse relationship between number of furcal setae and mineralization of the lakes was observed clearly. Artemia populations from the lakes Nevidim and Bolshoye Kureynoye were characterized by maximum number of setae on furca. The length of the body and the length of abdomen, on the contrary, had a tendency to increase with increasing of salinity. Linear Artemia characteristics from the lakes Maloye and Bolshoye Medvezhye were above the ones.

These regularity was confirmed in calculation of mean values for all seasons (see App. 19).

On the based of morphometric characteristics different Artemia populations cluster analysis was performed. The resulting dendrograms of similarity allowed

to present the nature of changes of parameters in compared groups of animals more clearly. Following picture was revealed after grouping lakes together according to morphometric characters:

1. In 2002 brine shrimps from eight investigated lakes formed three differentiated groups (Fig. 28). The first cluster consisted of Artemia populations from high-mineralized the lakes Maloye Medvezhye, Bolshoye Medvezhye and Ebeyty. Artemia populations from the lakes Ulzhay and Cherdynskoye with

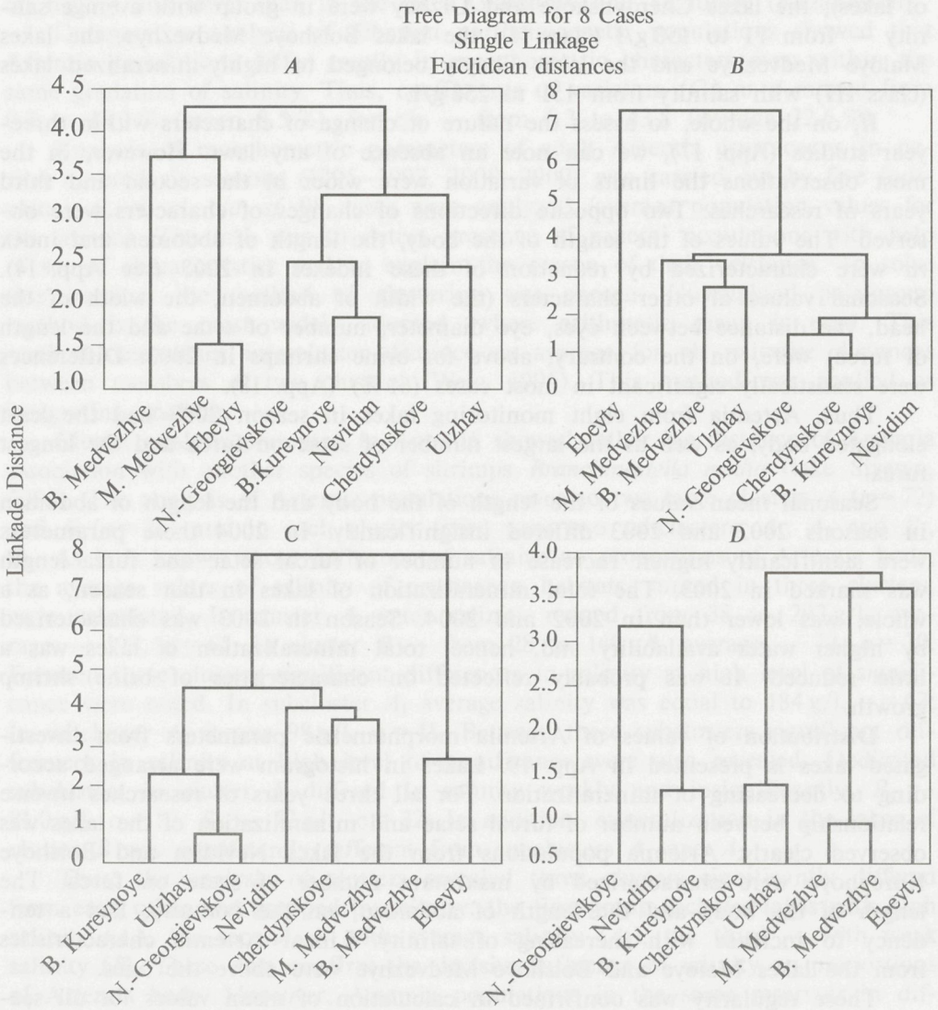


Fig. 28. Dendrogram of similarity constructed on basis morphometric characteristics of Artemia in different growing seasons.
A — 2002; *B* — 2003; *C* — 2004; *D* — 2002–2004.

average salinity were in the second cluster. Artemia shrimps from low-mineralized lakes Bolshoye Kureynoye, Novo-Georgievskoye and Nevidim joined the third cluster. Thus, there was a tendency to grouping Artemia of studied lakes according to our classification with use of degree of water mineralization.

2. In 2003 clustering of the lakes was like to 2002 (see Fig. 28). The first cluster was formed from Artemia populations of high-mineralized lakes (Ebeyty, Maloye Medvezhye and Bolshoye Medvezhye). The basis of the second cluster consisted of Artemia populations from the lakes with average salinity (Cherdynskoye, Ulzhay, Novo-Georgievskoye). The third cluster consisted of Artemia populations from low-salinity lakes (Bolshoye Kureynoye and Nevidim).

3. In 2004 all lakes were divided clearly into groups according to their degree of mineralization (see Fig. 28). The basis of the first cluster comprised of Artemia populations of high-mineralized lakes Ebeyty, Cherdynskoye, Maloye Medvezhye and Bolshoye Medvezhye. Artemia populations in the lakes with average salinity were the bases of second cluster. Artemia from low-mineralized lake Bolshoye Kureynoye were the most distant from the rest of populations.

Thus, after analyzing the grouping of different Artemia populations from eight monitoring lakes in south of Western Siberia on the basis of morphometric characters, patterns of differentiation according to total mineralization of lakes were found. This fact confirms the conclusion of substantial effect of salinity on Artemia growth.

Morphometric measurements of two bisexual Artemia populations from Khakasia and Tuva were performed. It was possible to carry out comparative analysis of Artemia growth from two fairly remote regions of Russia. Due to the fact that Artemia from the lakes Svatikovo and Tus form bisexual populations and shrimps from West Siberian lakes are parthenogenetic organisms, in comparative analysis only females were involved. After comparing of growth rates they are indicated that females from lake Svatikovo (Tuva) were larger than females from other studied Siberian reservoirs. Differences of analyzed characteristics were significant in 70 % of cases. Differences of female morphometric parameters in lake Tus (Khakasia) and lakes in south of Western Siberia were not reliable.

Cluster analysis of Artemia morphometric characters from two lakes in Khakasia and eight lakes in south of Western Siberia revealed following: Artemia populations from lake Tus with average mineralizatiom and low-mineralized Bolshoye Kureynoye lake were grouped in one cluster; Artemia from Svatikovo with high salinity entered the cluster with average salinity (Fig. 29).

Artemia populations from the lakes Svatikovo and Tus should be characterized by greater genetic affinity due to geographic proximity and possible exchange of genes. However, cluster analysis led to do the conclusion that morphometric parameters of crustaceans more depend on paratypic component than their genetic constitution.

Cluster analysis of female morphometric parameters (average values of 12 plastic and 2 meristic characters within 4 years of study 24 lakes situated in territory from the Urals to Altai) showed a clear separation of studied lakes

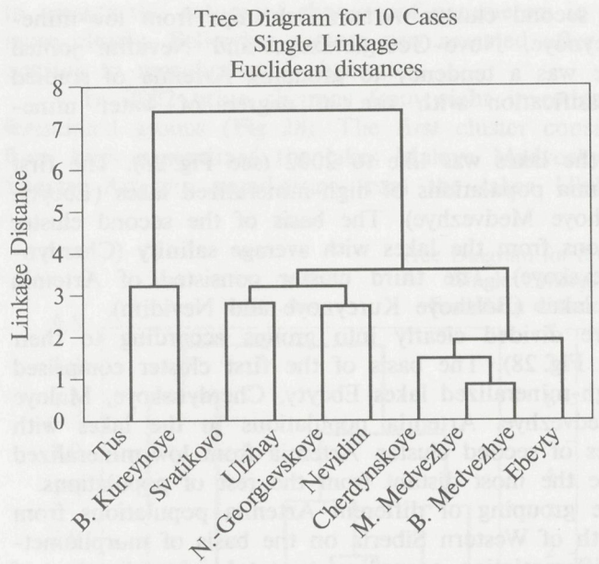


Fig. 29. Dendrogram of similarity constructed on the morphometric parameters of the Artemia populations from Khakasia, Tuva, Kurgan and Omsk regions.

into three significantly differing groups according to the degree of mineralization of reservoirs: high, medium and low-mineralized (Fig. 30). The first cluster was formed by Artemia populations from lakes with salinity from 63 to 173 g/l. The average salinity was 107.00 ± 9.77 g/l with coefficient of variation 35 %. The second cluster combined Artemia which habited in lakes with salinity from 90 to 263 g/l, on average 165.0 ± 10.71 g/l with coefficient of variation 27 %. In the third cluster there were Artemia populations from lakes with salinity from 27 to 90 g/l, on average 61.00 ± 4.48 g/l, the coefficient of variation was 27 %.

Obtained regularities allowed to trace the influence of total mineralization of water reservoirs as the main morfogenesis factor on brine shrimp growth and development.

Artemia habitats are often characterized by extreme environmental conditions. Many abiotic factors such as temperature, the ratio of ions, oxygen content, pH and total mineralization exert influence on formation of Artemia body proportions. However, the last factor was considered as dominant by many scientists.

Cluster analysis showed that grouping of investigated lakes on morphometric characters was based on limiting factor of Artemia existence — salinity. In all dendrograms of similarity one cluster combined Artemia populations from relatively high-mineralized lakes, the salinity varied from 151 to 250 g/l. The second cluster was composed mainly from lakes with medium salinity which varied from 71 to 150 g/l. The third cluster was formed by relatively low-mineralized lakes with salinity less than 70 g/l. Thus, the salinity of environment, being a significant factor in formation of biocenosis hypersaline lake is also very important in determination the individual body proportions of Artemia from Siberian populations.

Above noted regularities are evident especially at grouping lakes according to degree of mineralization into three graduations and calculating mean values for these grades (App. 20). According to these data, dependence of values of

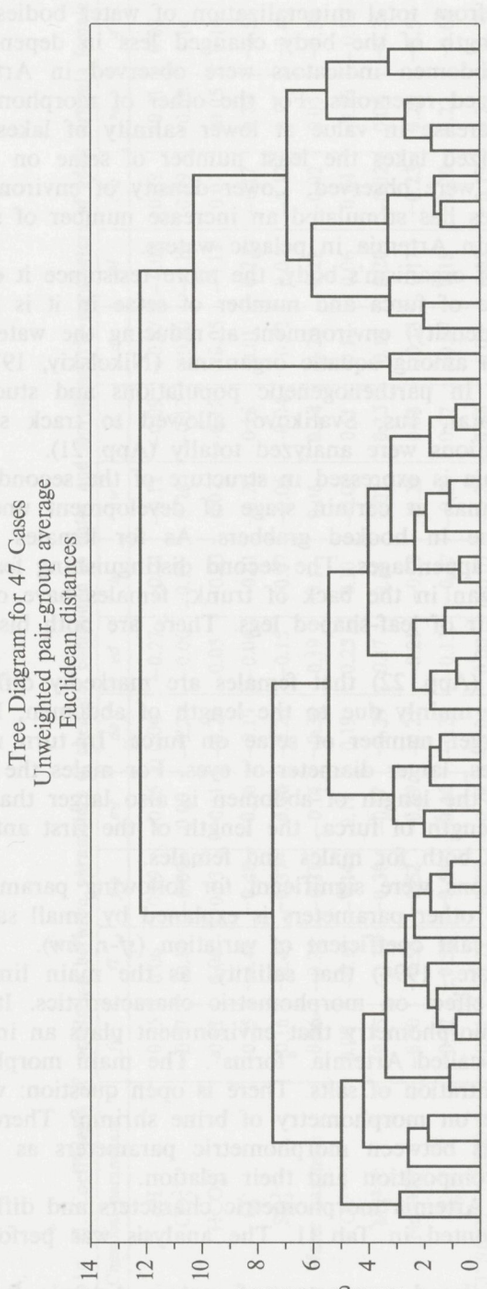


Fig. 30. Dendrogram of similarity constructed on morphometric data. On abscissa axis — the name of Lake/year of research/salinity, g/l.

linear and furcal characteristics from total mineralization of water bodies was visible particularly clear. The length of the body changed less in depend on salinity. Larger the length of abdomen indicators were observed in Artemia from the group of high-mineralized reservoirs. For the other of morphometric characters of crustaceans, an increase in value at lower salinity of lakes was noted. In group of high-mineralized lakes the least number of setae on furca and the smallest length of furca were observed. Lower density of environment for relatively low-mineralized lakes has stimulated an increase number of setae; their main function is to maintain Artemia in pelagic waters.

It is known the larger area of organism's body, the more resistance it exerts at immersing into water. Increase of furca and number of setae in it is a response to decrease of viscosity (density) environment at reducing the water salinity. This fact is quite common among aquatic organisms (Nikolskiy, 1974).

The presence of rare males in parthenogenetic populations and study of three bisexual populations (Tanatar, Tus, Svatikovo) allowed to track sexual variability of Artemia. 37 populations were analyzed totally (App. 21).

Sexual dimorphism in Artemia is expressed in structure of the second pair of antennas. These male's antennas at certain stage of development undergo sexual differentiation and become in hooked grabbers. As for females these antennas are reduced in sensory appendages. The second distinguishing feature: males have paired copulatory organ in the back of trunk; females have ovisac located just after the eleventh pair of leaf-shaped legs. There are both bisexual and parthenogenetic races.

In general, it can be noted (App. 22) that females are markedly different from males by larger body sizes, mainly due to the length of abdomen, larger width of abdomen and head, larger number of setae on furca. In turn males have greater distance between eyes, larger diameter of eyes. For males the ratio between the length of furca and the length of abdomen is also larger than for females. Such indicators as the length of furca, the length of the first antenna and index *ra* have similar values both for males and females.

Differences in body proportions were significant for following parameters: *tl*, *al*, *cl*, *ra*, *f/a*. Unreliability of other parameters is explaned by small sample (*aw*, *de*, *ed*, *fl*, *la*, *hw*) or significant coefficient of variation (*sf-r*, *hw*).

It is known (Pilla, Beardmore, 1994) that salinity, as the main limiting factor, has the most significant effect on morphometric characteristics. It was shown in number of studies on morphometry that environment plays an important role in determination of so-called Artemia "forms". The main morphogenesis factor for Artemia is concentration of salts. There is open question: which of salts have a decisive influence on morphometry of brine shrimp? Therefore, we conducted correlation analysis between morphometric parameters as water salinity in general as with salt composition and their relation.

The degree of correlation of Artemia morphometric characters and different environmental conditions is presented in Tab. 11. The analysis was performed on averaged values.

Comparing the values of analyzed parameters of mature Artemia females and lake salinity during the harvest, correlation coefficients r_{xy} between sali-

Table 11. Coefficients of correlation between parameters of chemical compound of water and morphometric parameters of adult Artemia female

Chemical parameters	*fw*	*fl*	*f/a*	*aw*	*de*	*ed*	*la*	*hw*	*tl*	*cl*	*al*	*c/a*	*ra*	*sf*
pH	−0.25	0.06	0.09	−0.26	0.00	−0.27	−0.21	−0.12	−0.09	−0.07	−0.08	0.02	−0.01	0.08
CO_3^{2-}	−0.17	−0.14	−0.09	0.00	−0.24	−0.06	0.19	0.26	−0.17	−0.10	−0.16	0.09	−0.09	0.14
HCO_3^-	−0.01	0.00	0.03	−0.11	−0.24	0.05	−0.03	0.07	−0.12	−0.05	−0.13	0.07	−0.05	0.14
Cl^-	−0.35	**−0.41**	**−0.48**	**−0.36**	−0.19	−0.06	−0.01	−0.20	0.15	0.01	**0.23**	−0.17	**0.20**	**−0.53**
SO_4^{2-}	−0.16	**−0.43**	**−0.37**	**−0.36**	−0.23	−0.15	−0.07	−0.05	−0.04	−0.12	0.04	−0.12	0.12	**−0.46**
Water hardness	−0.26	−0.22	−0.31	−0.14	**−0.36**	0.19	0.17	0.06	**0.24**	**0.20**	**0.22**	−0.02	0.05	**−0.38**
Ca^{2+}	0.08	−0.10	−0.14	0.17	0.19	0.23	0.10	−0.07	0.11	0.12	0.06	0.04	−0.03	−0.12
Mg^{2+}	−0.25	−0.21	**−0.30**	−0.17	**−0.39**	0.17	0.16	0.07	**0.23**	0.18	**0.20**	−0.02	0.04	**−0.39**
$Na^+ + K^+$	−0.30	**−0.53**	**−0.52**	**−0.49**	−0.21	−0.21	−0.13	−0.25	0.03	−0.13	0.17	**−0.23**	**0.25**	**−0.57**
Σ_i	−0.32	**−0.52**	**−0.54**	**−0.46**	−0.27	−0.13	−0.07	−0.20	0.07	−0.07	**0.18**	**−0.20**	**0.22**	**−0.60**
$Cl^-/(CO_3^{2-} + HCO_3^-)$	−0.11	−0.27	**−0.38**	−0.24	−0.04	0.00	−0.07	−0.26	**0.26**	0.07	**0.32**	**−0.19**	**0.21**	**−0.38**
Cl^-/CO_4^{2-}	−0.24	0.16	0.06	−0.18	−0.18	−0.09	−0.26	−0.13	−0.12	−0.04	−0.13	0.07	−0.08	−0.02
$SO_4^{2-}/(CO_3^{2-} + HCO_3^-)$	−0.11	**−0.41**	**−0.38**	**−0.34**	−0.09	−0.17	−0.08	−0.17	0.07	−0.08	0.16	**−0.18**	**0.18**	**−0.49**
Mg^{2+}/Ca^{2+}	−0.03	−0.08	−0.08	−0.24	−0.30	−0.07	−0.03	0.05	−0.03	−0.10	0.03	−0.08	0.09	0.01
$(Mg^{2+}+Ca^{2+})/(Na^++K^+)$	0.13	0.13	0.07	0.22	0.19	0.25	0.03	0.00	0.02	−0.02	0.04	−0.05	0.04	0.10
$Cl^-/(Mg^{2+}+Ca^{2+})$	−0.06	−0.24	−0.24	−0.22	0.19	**−0.33**	−0.21	−0.25	−0.12	**−0.20**	−0.01	−0.13	0.15	−0.09
$Cl^-/(Na^++K^+)$	0.03	0.12	0.05	0.20	0.23	0.22	0.02	−0.03	0.02	−0.02	0.05	−0.06	0.05	0.09

Note. The fat font designates significant connections at $p < 0.05$. The units of parameters are given in Tab. 9.

nity, content and ratio of ions (y) and main Artemia morphometric characteristics (x) were obtained.

Such factors as acidity (pH), content of sodium and carbonate, concentration of calcium ions and ratio Cl^-/SO_4^{2-}, Mg^{2+}/Ca^{2+}, $(Mg^{2+} + Ca^{2+})/(Na^+ + K^+)$ and $Cl^-/(Na^+ + K^+)$ had no significant effect on parameters of crustacean growth.

There was not significant correlation of any considered factors with parameters such as the width of furca (possibly due to small sample, because $n = 19$), the length of the first antenna and the width of the head (sample $n = 37$).

Water salinity (amount of ions) and ions determining salt composition: the amount of sodium and potassium, chlorides, sulfates, magnesium have the greatest impact on parameters of growth.

The length of the body of Artemia was in a weak positive relationship with water hardness due to magnesium content and the ratio of ions $Cl^-/(CO_3^{2+} + HCO_3^-)$. The length of cephalothorax was in weak positive relationship with water hardness and in negative relationship with ratio of ions $Cl^-/(Mg^{2+} + Ca^{2+})$. The length of abdomen was in weak positive relation with chlorides, hardness, magnesium, salinity and ratio of ions $Cl^-/(CO_3^{2+} + HCO_3^-)$.

The length of furca was in weak negative relationship with chlorides, sulfates and with ratio $SO_4^{2-}/(CO_3^{2+} + HCO_3^-)$ and in significant negative correlation with salinity in general and with the amount of ions $Na^+ + K^+$.

According to coefficients *ra* and *c/a* chlorides, potassium and sodium, sum of ions in whole and also ratio of ions $Cl^-/(CO_3^{2+} + HCO_3^-)$ and $SO_4^{2-}/(CO_3^{2+} + HCO_3^-)$ had positive effect on proportions of the body in direction of increasing the length of abdomen, but this relationship was weak. On the contrary, furcal index *f/a* was in close negative correlation with chlorides, sulfates, magnesium, sodium and potassium, sum of ions in whole and with ratio $Cl^-/(CO_3^{2+} + HCO_3^-)$ and $SO_4^{2-}/(CO_3^{2+} + HCO_3^-)$.

The width of abdomen correlated negatively with chlorides, sulfates, with amount of ions $K^+ + Na^+$, with salinity in general and with ratio $SO_4^{2-}/(CO_3^{2+} + HCO_3^-)$.

The distance between eyes was in weak negative correlation with hardness of water due to magnesium content. The only significant negative correlation was found between diameter of eyes and ratio of ions $Cl^-/(Mg^{2+} + Ca^{2+})$.

The highest values of these relations belonged to setae on furca. This parameter correlated negatively with almost half of analyzed factors: Cl^- ($r = -0.53$), SO_4^{2-} ($r = -0.46$), hardness ($r = -0.38$), Mg^{2+} ($r = -0.39$), $Na^+ + K^+$ ($r = -0.57$), the amount of ions ($r = -0.60$), $Cl^-/(CO_3^{2+} + HCO_3^-)$ ($r = -0.38$), $SO_4^{2-}/(CO_3^{2+} + HCO_3^-)$ ($r = -0.49$).

Relationship, in general significant, between water salinity and morphometric parameter is showed in Fig. 31. In Fig. 32 significant (r from 0.5 to 0.7) reliable connection between components of salt composition and morphometric parameters is demonstrated. The figures show that all significant communications belong only to furcal characteristics (*sf*, *fl*, *f/a*) on one hand and salinity, the amount of sodium and potassium chlorides to another hand.

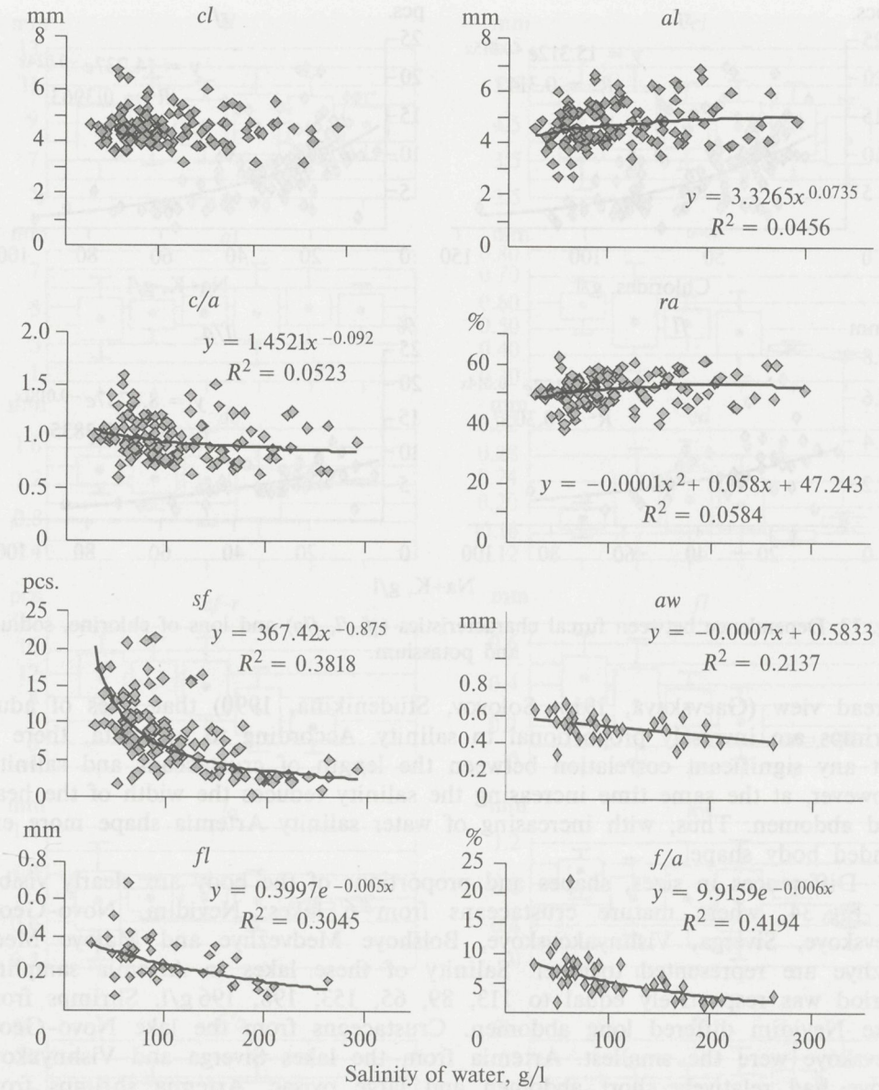


Fig. 31. Dependence of morphometric parameters of Artemia shrimps from salinity.

The effect of salinity on morphometric parameters of Artemia more clearly is presented in Fig. 33, where all parameters of crustaceans were grouped according to sum ions of lake water in 6 classes: < 50, 51–70, 71–130, 131–190, 191–250, > 250 g/l. Average parameters for each group of salinity characterize clear negative correiation with following parameters: *aw*, *sr*, *fl*, *f/a*, *hw* and positive relationship with index *ra*. Thus, our studies partly refute the wide-

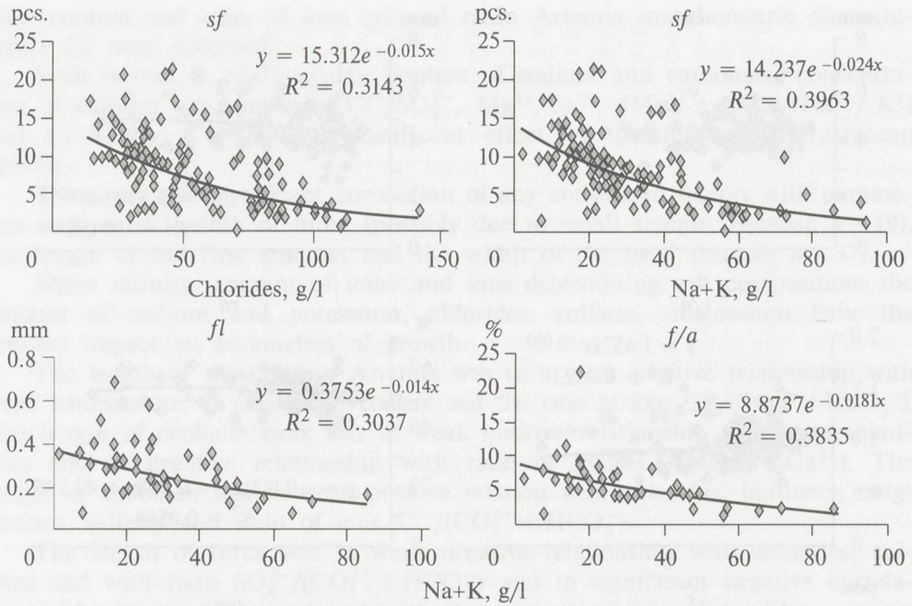


Fig. 32. Dependence between furcal characteristics (*sf*, *fl*, *f/a*) and ions of chlorine, sodium and potassium.

spread view (Gaevskaya, 1916; Solovov, Studenikina, 1990) that sizes of adult shrimps are inversely proportional to salinity. According to our data, there is not any significant correlation between the length of crustaceans and salinity. However, at the same time increasing the salinity reduces the width of the head and abdomen. Thus, with increasing of water salinity Artemia shape more extended body shape.

Differences in sizes, shapes and proportions of the body are clearly visible in Fig. 34, where mature crustaceans from 6 lakes: Nevidim, Novo-Georgievskoye, Siverga, Vishnyakovskoye, Bolshoye Medvezhye and Maloye Medvezhye are represented together. Salinity of these lakes in Artemia sampling period was respectively equal to 113, 89, 65, 153, 198, 196 g/l. Shrimps from lake Nevidim differed long abdomen. Crustaceans from the lake Novo-Georgievskoye were the smallest. Artemia from the lakes Siverga and Vishnyakovskoye had relatively short abdomen and large ovisac. Artemia shrimps from the lakes Maloye Medvezhye and Bolshoye Medvezhye have the same proportions and sizes; they differ from other crustaceans with triangular shape of ovisac, completely filled cysts. Crustaceans from different populations varied a little bit by the length of the body except Artemia from lake Novo-Georgievskoye, where significant differences were observed in structure of caudal part of the body. Shrimps, inhabited in water with high salinity, had poorly developed furca: furcal branches were poorly expressed (index *f/a* from 2 to 4 %), they were not separated from telson and had 2–3 setae (the lakes Bol-

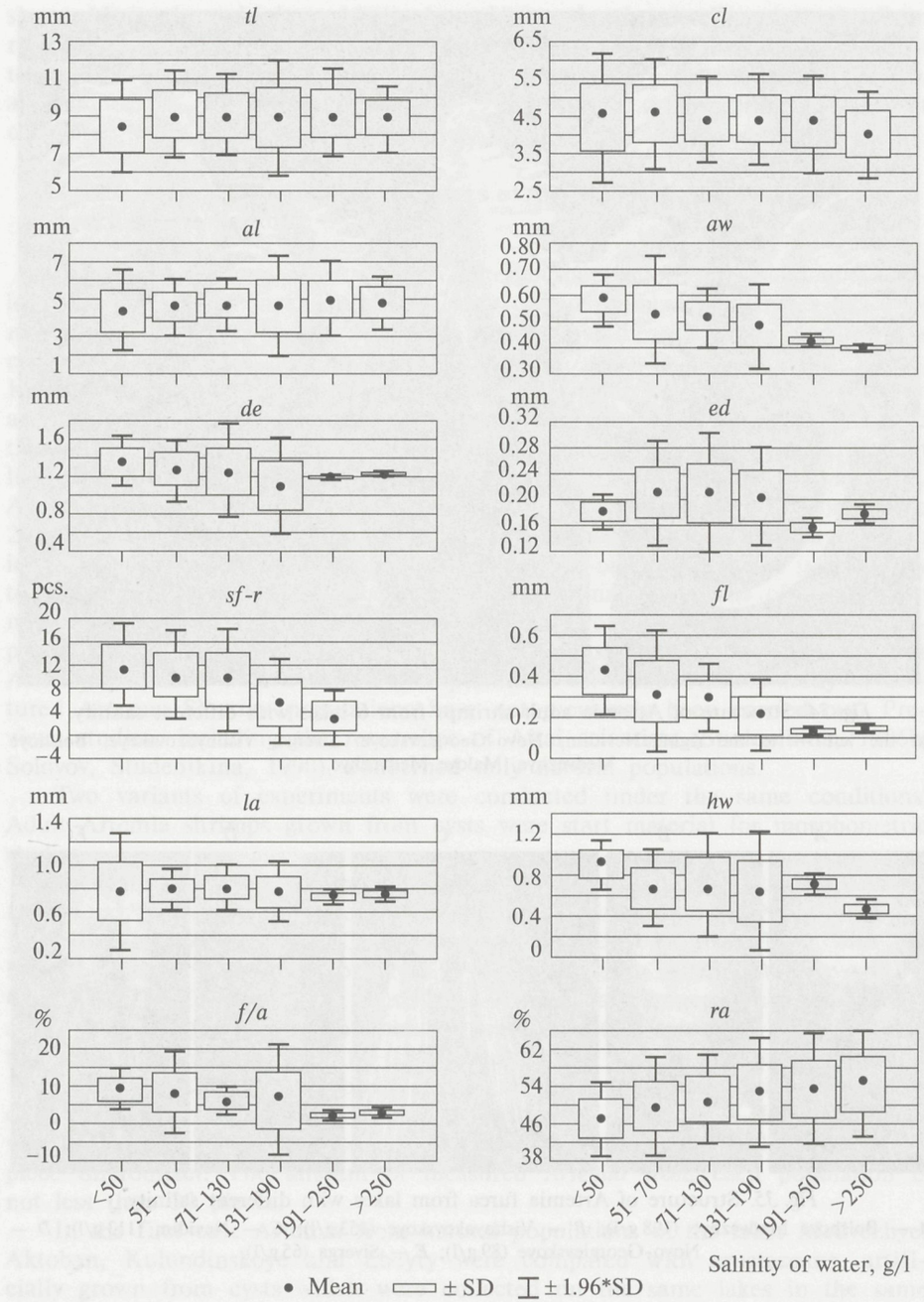


Fig. 33. Average values of parameters at different salinity of environment.

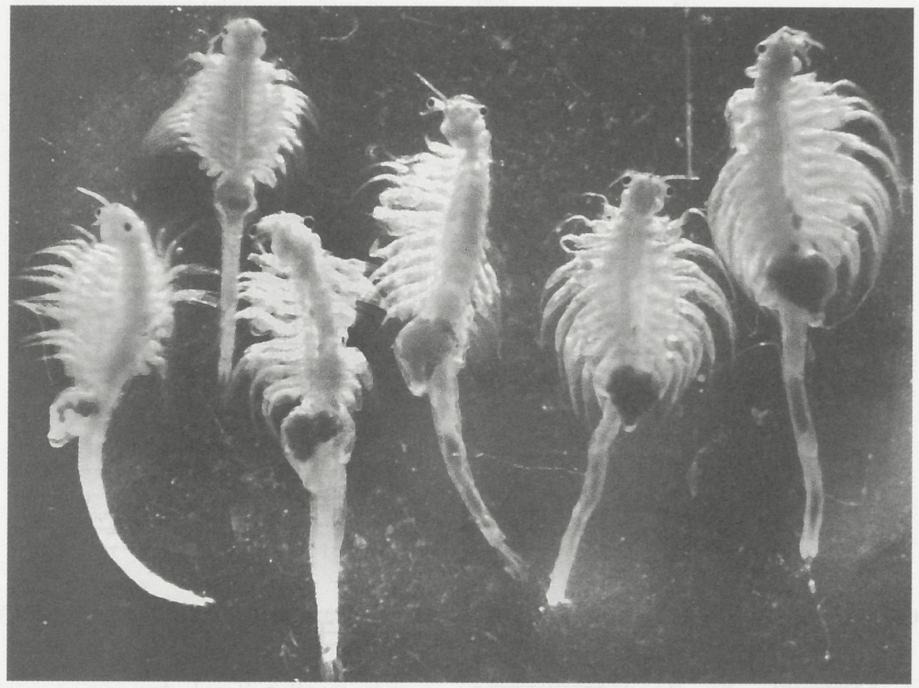


Fig. 34. Structure of Artemia adult shrimps from 6 lakes with different salinity.
At the left — to the right: Nevidim, Novo-Georgievskoye, Siverga, Vishnyakovskoye, Bolshoye Medvezhye, Maloye Medvezhye.

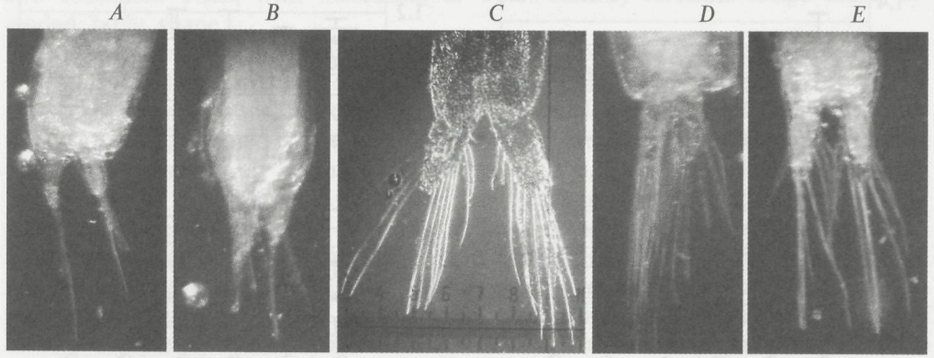


Fig. 35. Structure of Artemia furca from lakes with different salinity.
A — Bolshoye Medvezhye (198 g/l); *B* — Vishnyakovskoye (153 g/l); *C* — Nevidim (113 g/l); *D* — Novo-Georgievskoye (89 g/l); *E* — Siverga (65 g/l).

shoye Medvezhye, Maloye Medvezhye, Vishnyakovskoye). For Artemia from reservoirs with less salinity furca was well developed: it was separated from telson, the length of furca was 5–7 % of the length of abdomen (index *f/a*), and number of bristles on average was 9–13. Reduction of furca and number of bristles on it with increase of salinity is demonstated in Fig. 35.

3.1.2.2. Morphological characteristics of Artemia shrimps grown in artificial conditions

Morphological studies of Artemia Siberian populations presented above allowed to draw the conclusion that salinity of environment is a major factor of morphogenesis. First of all, according to these studies, as well as researches conducted earlier (Litvinenko et al., 2002, 2007; Boyko et al., 2002; Boyko, Kutyreva, 2005), water salinity has the greatest influence on structure of furca and abdomen. Cluster analysis of Artemia morphometric parameters showed that populations remoted on considerable distances (up to 2200 km in straight line), grouped together according to salinity, rather than geographical location. As salinity in investigated lakes varied greatly and it was in range from 34 to 299 g/l, it was not possible to set genetic variability of phenotype. In order to identify the species and more effective recognition of populations it is necessary to analyze the variability of phenotypes in the same conditions of salinity. To neutralize the effect of salinity on growth and proportions of crustaceans, experiments on artificial cultivation of shrimps from different cysts of Artemia Asian populations were conducted. Experiments on morphometric study of cultured Artemia Siberian populations have not previously been carried out. Previous studies, including the researches of Altai scientists (Studenikina, 1986b; Solovov, Studenikina, 1990), concerned only natural populations.

Two variants of experiments were conducted under the same conditions. Adult Artemia shrimps grown from cysts were start material for morphometric studies.

Incubation of cysts was carried out in taper vessels under artificial lighting (1000 Lux), at temperature 25 °C, aeration, in saline solution (NaCl — 5 g/l, $NaHCO_3$ — 2 g/l) for 36 h. Cultivation was conducted in glass flasks with volume 2 liters, in saline solution (NaCl — 31.08, $MgSO_4$ — 7.74, $MgCl_2$ — 6.09, $CaCl_2$ — 1.53, KCl — 0.97, $NaHCO_3$ — 2 g/l) at temperature about 25 °C, aeration, feeding with dry micronized rice brans (daily rate is 0.1 mg/ind. at the beginning of cultivation to 0.4 mg/ind. at the end). Density of nauplii is 100 ind./l, due to shrimps growth density was diluted till 10–20 ind./l. Crustaceans reached maturity were fixed in 4 % solution of formalin. Lab processing was carried out under stereoscopic microscope MBS-10 equipped with an eyepiece micrometer. The amount of measured *Artemia* from each population is not less than 30 pieces.

In the first case Artemia from natural populations of the lakes Medvezhye, Aktoban, Kulundinskoye and Ebeyty were compared with crustaceans, artificially grown from cysts which were collected on the same lakes in the same season when the natural populations were investigated. In the second case of

experiments shrimps grown from cysts of Siberian populations (Nevidim, Kulundinskoye), Kazakhstan (Teke), Mongolian (Bayan-Tuhum) and Chinese populations (*A. sinica*) were compared. Cysts of last three populations were kindly provided by employees of Artemia Referent Center (ARC) (Ghent University, Ghent, Belgium).

Comparison of cultured and natural Artemia populations

Comparative characteristics of morphometric parameters of cultured Artemia and shrimps from natural reservoirs: the lakes Aktoban, Kulundinskoye, Medvezhye, Ebeyty with total mineralization 95, 104, 193, 264 g/l is presented in Tab. 12. Natural Artemia populations from lakes had higher values of the length of the body, length of abdomen and index *ra* in compare with laboratory Artemia samples. Other indicators (*aw*, *de*, *ed*, *sf*, *fl*, *la*, *hw*) were higher in cultured Artemia. In natural Artemia populations of the lakes Medvezhye and Ebeyty number of furcal setae and length of furca were significantly lower. The analysis of significance of differences of morphometric characters between grown crustaceans and selected from natural conditions showed following:

— at paired comparison there were no significant differences in average selected indicators in all feachers of Artemia from the lakes Aktoban and Kulundinskoye;

— differences between two compared Artemia samples from lake Medvezhye were significant at 27 % from number of indicators involved in analysis;

— differences of morphometric parameters of adult Artemia females from lake Ebeyty were significant at 91 % from number of pairs of comparisons.

Thus, the more salinity of natural habitat differes from artificial the more significant were morphometric differences of crustaceans.

Level of variability analyzed Artemia parametrs in natural and artificial conditions was insignificant and exceed rarely 20 %. Variation of most indicators was higher in Artemia from natural environment. Number of setae on furca and length of furca in all studied Artemia populations were the most variable.

Comparison of morphometric parameters of crustaceans grown in laboratory with Artemia from natural conditions has clearly demonstrated the influence of salinity on growth. A significant difference between the salinity of natural lakes and culture environment was primarily affected on furcal characteristics as the most sensitive to salinity. The number of setae and the length of furca were higher in artificial cultivation. The lower density of environment, characterized for water with less salinity, stimulated an increase the number of setae to maintain Artemia in water column.

In natural environments together with increase of the length of the body and length of abdomen there was a decrease indicators of body width (*aw*, *hw*, *de*).

Thus, under natural conditions Artemia had more elongated body; that fact was probably due to not only salinity but also with greater mobility of crustaceans in natural reservoirs and nature of feeding.

Under laboratory conditions salinity and other factors (temperature, pH, light, diet, etc.) were maintained at an optimum level for the growth of crus-

Table 12. **Morphometric parameters of Artemia which brought up in laboratory conditions ($M \pm m$)**

Index	Lake			
	Aktoban	Kulundinskoye	B. Medvezhye	Ebeyty
	The average salinity of lakes in the season of shrimps and cysts sampling, g/l			
	95	104	193	264
tl, mm	7.44 ± 0.22 (8.70 ± 0.13)*	8.16 ± 0.12 (8.62 ± 0.15)	8.33 ± 0.12 (10.62 ± 0.12)	7.66 ± 0.13** (8.79 ± 0.09)
al, mm	3.77 ± 0.11 (4.83 ± 0.09)	4.34 ± 0.08 (4.62 ± 0.12)	3.97 ± 0.11 (6.45 ± 0.08)	3.87 ± 0.09** (5.14 ± 0.07)
aw, mm	0.51 ± 0.02 (0.50 ± 0.01)	0.50 ± 0.01 (0.43 ± 0.01)	0.60 ± 0.01 (0.44 ± 0.01)	0.53 ± 0.01** (0.40 ± 0.01)
de, mm	1.26 ± 0.04 (1.32 ± 0.03)	1.29 ± 0.02 (1.10 ± 0.02)	1.44 ± 0.02 (1.21 ± 0.02)	1.15 ± 0.02 (1.11 ± 0.01)
ed, mm	0.22 ± 0.01 (0.21 ± 0.001)	0.20 ± 0.01 (0.21 ± 0.01)	0.23 ± 0.01 (0.20 ± 0.001)	0.20 ± 0.01** (0.16 ± 0.001)
sf-r, pcs.	10.10 ± 1.27 (7.54 ± 0.28)	7.36 ± 0.34 (3.69 ± 0.42)	13.36 ± 0.24** (2.58 ± 0.13)	7.92 ± 0.24** (3.08 ± 0.12)
sf-l, pcs.	10.08 ± 1.23 (7.50 ± 0.030)	7.32 ± 0.35 (3.63 ± 0.42)	13.16 ± 0.27** (2.58 ± 0.11)	7.48 ± 0.23** (3.01 ± 0.14)
fl, mm	0.41 ± 0.06 (0.24 ± 0.01)	0.30 ± 0.01 (0.16 ± 0.01)	0.30 ± 0.01 (0.11 ± 0.01)	0.29 ± 0.01** (0.14 ± 0.01)
la, mm	0.81 ± 0.03 (0.78 ± 0.02)	0.86 ± 0.02 (0.64 ± 0.03)	0.93 ± 0.01 (0.79 ± 0.01)	0.77 ± 0.01** (0.66 ± 0.01)
hw, mm	0.52 ± 0.01 (0.52 ± 0.01)	0.57 ± 0.01 (0.52 ± 0.02)	0.61 ± 0.01 (0.54 ± 0.01)	0.60 ± 0.01** (0.48 ± 0.01)
ra, %	50.28 ± 0.77 (55.45 ± 0.46)	53.10 ± 0.49 (55.70 ± 0.61)	47.6 ± 1.08** (60.84 ± 0.43)	50.28 ± 0.46** (58.39 ± 0.44)

Note. * Values of parameters from habitat are specified in brackets; ** distinctions are significant ($p < 0.01$).

taceans. While in nature within one growing season parameters of environment vary in sufficiently wide limits.

The total phenotypic variation consists of genotypic and paratypic variances. Under artificial cultivation influence of paratypic or environmental variance is slightly reduced due to maintain of optimum constant conditions for Artemia growth. *In vivo* effect of environment on total phenotypic variability of crustaceans is high enough.

Comparison of morphometric parameters of shrimps from reservoirs of Asian continent, grown in laboratory

Morphometric analysis of Artemia from the lakes Kulundinskoye (Russia), Nevidim (Russia), Teke (Kazakhstan), Bayan-Tuhum (Mongolia) and *A. sinica* (China) grown in laboratory is presented in Tab. 13.

Level of variability of analyzed characteristics, in general, was insignificant and rarely exceeded average level. The length of furca and number of furcal setae were the most variable. The coefficient of variation of furca length varied from 8 (Kulundinskoye) to 24 % (Bayan-Tuhum), the number of furcal

Table 13. Comparison of morphological parameters of shrimps which brought up Artemia cysts from the Asian populations ($M \pm m$)

Lake and species	*il*, mm	*al*, mm	*aw*, mm	*de*, mm	*ed*, mm	*sf-r*, pcs.	*fl*, mm	*la*, mm	*hw*, mm	*ra*, %	*c/a*
Nevidim	10.11±0.04	4.85±0.04	0.54±0.01	1.34±0.02	0.24±0.01	9.90±0.42	0.25±0.01	1.02±0.01	0.81±0.01	47.94±0.41	1.09±0.02
	9.8–10.5	4.5–5.1	0.45–0.65	1.2–1.5	0.2–0.25	6.0–14.0	0.2–0.35	0.9–1.15	0.75–0.9	43.7–52.0	0.92–1.29
Kulundinskoye	8.65±0.08	4.20±0.03	0.50±0.01	1.16±0.02	0.19±0.01	8.23±0.53	0.29±0.01	0.83±0.01	0.65±0.01	48.74±0.63	1.06±0.03
	8.0–9.25	4.0–4.42	0.42–0.55	1.0–1.3	0.15–0.25	2.0–16.0	0.25–0.35	0.72–0.90	0.50–0.80	43.5–54.9	0.82–1.30
Teke	9.10±0.10	4.8±0.07	0.53±0.01	1.35±0.03	0.24±0.01	9.50±0.57	0.28±0.01	0.80±0.01	0.74±0.03	53.05±0.97	0.90±0.04
	7.95–9.90	4.0–5.52	0.43–0.63	0.92–1.62	0.18–0.28	3.0–17.0	0.22–0.38	0.58–0.98	0.47–1.02	40.7–61.3	0.63–1.46
Bayan-Tuhum	9.00±0.13	4.60±0.10	0.70±0.01	1.38±0.02	0.24±0.01	3.03±0.19	0.24±0.01	1.04±0.02	1.12±0.02	51.35±1.21	0.98±0.04
	7.55–10.59	3.63–5.6	0.58–0.83	1.16–1.66	0.19–0.29	2.0–6.0	0.15–0.35	0.79–1.21	1.00–1.30	40.3–68.6	0.46–1.48
A. sinica	8.56±0.12	4.76±0.09	0.51±0.01	1.21±0.01	0.21±0.01	7.10±0.51	0.20±0.01	0.80±0.02	0.78±0.03	55.77±1.07	0.81±0.04
	7.5–10.0	3.75–6.00	0.43–0.63	1.1–1.41	0.15–0.25	2.0–13.0	0.15–0.25	0.58–0.98	0.55–1.05	41.7–64.4	0.55–1.40

Note. Above line – $M \pm m$, below line – limits of parameter fluctuations.

setae was from 24 (Nevidim) to 40 % (*A. sinica*). The other parameters were more stable.

In general, the morphometric parameters of Artemia Asian populations in 71 % cases differed significantly (App. 23). Artemia from two lakes Bayan-Tuhum and Kulundinskoye showed the highest level of distinction (all 10 parameters). Crustaceans from the lakes Teke and Bayan-Tuhum differed the least of all (4 from 10 parameters). Artemia from lake Kulundinskoye showed the most significant differences with respect to all analyzed populations (83 %), crustaceans from Teke lake — the smallest (58 %).

Comparison of morphometric parameters studied Russian and foreign populations showed following:

— *A. sinica* (China) differed significantly from Siberian populations by 65 % analyzed pairs of characteristics;

— bisexual population from lake Bayan-Tuhum (Mongolia) was significantly different from Siberian populations of crustaceans under 80 % analyzed pairs of characteristics;

— parthenogenetic population of lake Teke (Kazakhstan) was significantly different from Siberian populations by 60 % analyzed pairs of signs.

The resulting patterns were confirmed under grouping studied populations with method of weighted pairwise average. Data on the degree of similarity on morphometric indices studied Artemia populations are shown in Fig. 36. The analysis of similarity dendrogram showed presence of two clusters. The first cluster has combined two Artemia populations from Siberian lakes (Nevidim and Kulundinskoye). The second cluster composed crustacean populations from the lakes Teke (Kazakhstan) and Bayan-Tuhum (Mongolia). The most distant under investigated morphometric parameters *A. sinica* joined to them.

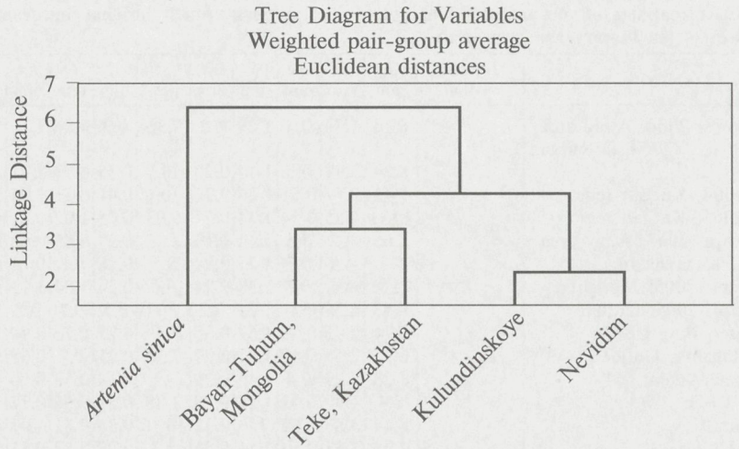


Fig. 36. Dendrogram of similarity of morphometric parameters of artificial brought up shrimps from the Asian populations (2005 year).

The study of *Artemia* growth parameters from different habitats in artificial cultivation has led to the conclusion that formation of phenotypic features of Artemia Asian populations depends on not only the environment but genetic characteristics of the object.

Comparative analysis of morphometric parameters of cultured Artemia shrimps with data of literature

Comparison was conducted with bisexual populations of American species *A. franciscana* and *A. persimilis* (Gajardo et al., 1998) and parthenogenetic populations from China, Greece, Namibia and Madagascar (Abatzopoulos et al., 1987; Triantaphyllidis et al., 1996; 1997a).

Comparison of morphometric parameters of Artemia from Siberia and other habitats showed that crustaceans from Greek, Chinese and Madagascar populations differed the largest sizes (Tab. 14). The main morphological parameters: the length of the body and the length of abdomen in Greek populations were within 12.19–13.77 and 6.44–7.46 mm, in Chinese — 11.71–14.1 and 6.2–8.15 mm, in Madagascar — 6.33 and 11.53 mm, respectively. For comparison, the largest cultured Artemia crustaceans from lake Nevidim had average length 10.1 mm, length of abdomen — 4.85 mm. At the length of the body studied populations of crustaceans (Siberian, Mongolian, Kazakhstan and *A. sinica*) were closed to American (*A. franciscana* and *A. persimilis*) and African populations. But cultured crustaceans of studied populations did not have such small sizes as mature females in lake Piura (5.98 mm in length). Despite the similarities in the length of the body, proportions of body for Asian and American populations are different. For American populations the length of cephalothorax predominates above the length of abdomen, this fact is evidenced by coefficients *ra* and *c/a*, equal 38.12–53.37 % (43.86 % — average among

Table 14. **Comparison of morphometric parameters of Artemia which brought up from different populations cysts (on literary and own data)**

Locality	Abbreviation	*tl*, mm	*al* mm	*aw* mm	*de* mm	*ed* mm	*sf* pcs.	*fl* mm	*la* mm	*hw* mm	*ra*, %	*c/a*
Kulundinskoye, 2004, Altay area		8.16	4.34	0.5	1.29	0.2	7.36	0.3	0.86	1.13	53.1	0.88
B. Medvezhye, 2004, Kurgan region		8.34	3.97	0.6	1.44	0.23	10.0	0.39	0.93	1.22	47.6	1.1
Aktoban, 2004, Kurgan region		7.44	3.77	0.51	1.26	0.22	10.1	0.41	0.81	1.04	50.63	0.97
Nevidim, 2005, Kurgan region		10.11	4.85	0.54	1.34	0.24	9.93	0.25	1.02	0.81	47.94	1.08
Kulundinskoye, 2005, Altay area		8.65	4.2	0.5	1.16	0.19	8.47	0.29	0.83	0.65	48.74	1.06
Teke, 2005, Kazakhstan		9.1	4.8	0.5	1.35	0.24	9.5	0.28	0.8	0.74	52.75	0.9
Bayan-Tuhum, 2005, Mongolia		9.0	4.6	0.7	1.38	0.24	6.6	0.24	1.04	1.12	51.11	0.96
Artemia sinica, 2005, China		8.53	4.76	0.51	1.21	0.2	7.07	0.2	0.7	0.8	56.12	0.79
San Francisco Bay, USA[1]		7.74	2.95	0.69	1.69	0.35	10.95	0.27	0.76	0.94	38.12	1.62
Salar de Atacama, Chile[1]		6.97	2.58	0.42	1.31	0.27	7.36	0.21	0.7	0.68	38.1	1.7
Buenos Aires, Argentina[1]		8.28	3.29	0.4	1.46	0.29	3.1	0.18	0.56	0.76	40.27	1.52
Pichilemu, Chile[1]		8.4	4.37	0.42	1.35	0.28	2.88	0.21	0.56	0.77	51.74	0.92
Macau, Brazil[1]		8.44	3.83	0.62	1.7	0.32	10.16	0.34	0.81	1.02	45.15	1.2
Los Vilos, Chile[1]		7.98	3.53	0.54	1.51	0.31	8.7	0.27	0.87	0.81	44.01	1.26
Rio Grande do Norte, Brazil[1]		7.56	3.18	0.61	1.42	0.29	11.21	0.27	0.78	0.9	41.94	1.38
Piura, Peru[1]		5.98	2.49	0.48	1.14	0.24	8.55	0.2	0.73	0.65	41.57	1.4
Madagascar, Madagascar[2]		11.53	6.33	0.66	1.8	0.29	7.9	0.27	1.2	0.93	54.9	0.82
Megalon Embolon, Greece[3]	MEM	13.9	7.45	0.84	2.13	0.33	5.19	0.35	1.52	1.13	53.6	0.87
Citros, Greece[3]	CIT	13.66	7.46	0.75	1.95	0.3	5.13	0.34	1.45	1.07	54.61	0.83
Polychnitos, Greece[3]	POL	13.77	7.4	0.79	2.04	0.3	5.26	0.34	1.46	1.1	53.74	0.86
Kalloni, Greece[3]	KAL	12.76	6.96	0.82	1.87	0.3	6.06	0.31	1.31	1.03	54.55	0.83
Aibi Lake, Xinjiang, China[3]	AIL	13.11	7.08	0.77	1.96	0.32	6.27	0.28	1.35	1.07	54	0.85
Balikum Lake, Xinjiang, China[3]	BAL	12.55	7.07	0.68	1.8	0.28	7.07	0.25	1.24	0.98	56.33	0.78
Kazakhstan (unknown source)[3]	CAT	12.98	6.93	0.79	1.85	0.31	9.53	0.49	1.27	1.01	53.39	0.87
Chengkou, Shandong, China	CHK	11.71	6.26	0.66	1.88	0.31	8.33	0.34	1.31	0.99	53.46	0.87
Dongjiagon, Liaoning, China[3]	DOJ	12.23	6.5	0.74	1.79	0.3	8.77	0.37	1.36	0.96	53.15	0.88
Hangu, Tianjin, China[3]	HAN	12	6.2	0.72	1.77	0.29	8.63	0.36	1.25	0.94	51.67	0.94
Pulandian, Liaoning, China[3]	PUL	12.45	6.61	0.71	1.8	0.29	8.73	0.36	1.32	0.96	53.09	0.88
Xuyu, Jiangsu, China[3]	XUW	13.73	7.34	0.82	2.24	0.37	6.5	0.35	1.58	1.07	53.46	0.87
Huanghua, Hebei, China[3]	HUA	12.99	6.96	0.74	1.97	0.32	7.03	0.35	1.46	1.05	53.58	0.87
Daban Lake, Xinjiang, China[3]	DAL	14.1	8.15	0.76	1.93	0.3	6.68	0.33	1.35	1.04	57.8	0.73
Swakopmund, Namibia[3]	NAM	9.68	4.63	0.77	1.63	0.27	8.84	0.49	1.2	0.92	47.83	1.09
All populations	min	5.98	2.49	0.4	1.14	0.19	2.88	0.18	0.56	0.65	38.1	0.73
	max	14.1	8.15	0.84	2.24	0.37	11.21	0.49	1.58	1.22	57.8	1.7
	average	10.43	5.34	0.64	1.64	0.28	7.746	0.31	1.07	0.95	50.25	1.02
Siberian populations	»	8.54	4.23	0.53	1.3	0.22	9.172	0.33	0.89	0.97	49.6	1.02
American population	»	7.669	3.28	0.52	1.45	0.29	7.864	0.24	0.72	0.82	42.61	1.38
Chinese, Greek, Madagascar population	»	12.9	6.98	0.75	1.92	0.31	7.139	0.34	1.36	1.02	54.09	0.85

[1] Gajardo et al., 1998.
[2] Triantaphyllidis et al., 1998.
[3] Triantaphyllidis et al., 1997b.

populations) and 0.87–1.70 (average 1.31). In Greek, Chinese and Madagascan populations, as well as in *A. sinica* proportions of the body shifted towards predominance the length of abdomen: the coefficients *ra* are from 51.7 to 57.8 % (average 54.1), *c/a* are from 0.73 to 0.94 (average 0.85). Artemia of Siberian populations are characterized by equal length of cephalothorax and abdomen: index *ra* is from 47.94 to 53.10 % (mean 49.60) and *c/a* is from 0.88

to 1.10 (average 1.02). For this indicator, shrimps from Namibia are also closer to Siberian populations (*ra* — 47.83; *c/a* 1.09). For all other indicators crustaceans from Siberian populations occupy an intermediate position between American and Chinese populations, except for the length of furca, which has similar values to Chinese populations, and number of setae (this parameter is the greatest for Siberian populations).

Comparison of morphometric parameters was conducted generally with help of cluster analysis (Fig. 37). All compared populations formed two clusters. The first claster joined American populations. In the second cluster there were two subclusters: the first subcluster unified Chinese, Greek, Madagascar and Kazakhstan populations; in the second subcluster there were Siberian and African (Namibia) populations. Bisexual population from Mongolia (Bayan-Tuhum) and *A. sinica* joined to the first subcluster at some distance. In general, despite the great difference in morphometric parameters between crustaceans of Siberian populations and populations of Chinese group, Siberian populations were closer to East (Old World) populations than to West (New World) ones. Morphometric analysis of cultured crustaceans allowed to detect differences between Artemia populations. Cluster analysis on crustacean morphometric indices showed differentiation of all studied populations into two groups according to geographic location of reservoirs. Bisexual Artemia populations of North and

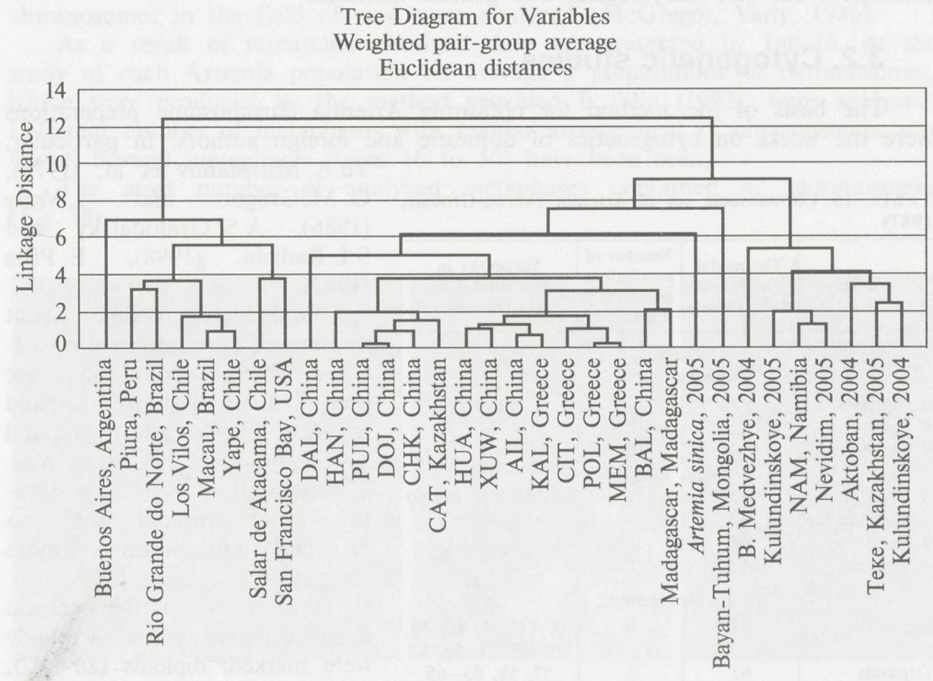


Fig. 37. Mean similarity dendrogram for morphometric parameters of different Artemia populations (on the own and literary data).

South America consisted the first group, parthenogenetic and bisexual populations from Asia, Europe and Africa were in the second one. Cultured crustaceans from cysts of Siberian populations on morphometric parameters formed general cluster with Asian group of populations.

Thus, due to study of Artemia morphometric parameters cumulative effect of genotype and environment on phenotype was clearly showed. According to our researches and numerous authors (Gajevskaya, 1916; Gilchrist, 1960; Voronov, 1979; Amat, 1980; D'Agostino, 1980; Wear, Haslett, 1987; Solovov, Studenikina, 1990; Triantaphyllidis et al., 1997b; El-Bermawi et al., 2004), salinity of habitat is a major cause of morphological differences of natural Artemia populations.

From all morphometric characters the most informative parameters, showing the effect of salinity on Artemia, are the length of furca and the number of setae on furca. Indices, showing the effect of genotype may possibly serve as ratio of abdomen to the body length and ratio of the length of cephalothorax to abdomen. The use of these indices to some extent allows to neutralize the impact of environmental factors on Artemia dimensional characteristics and to focus on study of allometric variation.

The above data showed impossibility of identifying Artemia species using only morphometric parameters. Therefore, the study of species belonging Artemia from Russian populations should be based not only on the use of morphological but also karyological and genetic methods.

3.2. Cytogenetic studies

The basis of the method for obtaining Artemia chromosome preparations were the works on cytogenetics of domestic and foreign authors, in particular, Yu.A. Mitrofanov et al. (1976), G. McGregor and J. Varly (1986), A.S. Grafodatsky and S.I. Radjabi (1998), E. Pilla (1992).

Table 15. **Chromosome set of Artemia (Abreu-Grobois, 1987)**

Species	The modal number of chromosomes	Number of populations containing aneuploids	Variability in the number of chromosomes
Bisexual			
New world			
A. franciscana	42	1	21–48
A. monica	42	0	42
A. persimilis	44	0	44
Old world			
A. tunisiana	42	1	42, 44, 46, 48, 50
A. tibetiana	42	—	—
A. sinica	42	—	—
A. urmiana	42	0	42
Parthenogenetic			
Diploids	42	4	40, 42, 44, 46, 48, 50, 52, 54, 56, 63
Triploids	63	3	57, 58, 63–65
Tetraploids	84	1	84, 89
Pentaploids	105	2	104–111

Published data about number of chromosomes of different Artemia populations are presented in Tab. 15. Diploid set ($2n$) of the most bisexual species was 42 chromosomes. The exception was *A. persimilis*, which diploid set was on two chromosomes more ($2n = 44$).

Within parthenogenetic forms different levels of ploidy were marked: diploids ($2n = 42$), triploids ($3n = 63$), tetraploids ($4n = 84$), pentaploids ($5n = 105$).

In some bisexual species such as *A. franciscana* and *A. tunisiana*, as well as in parthenogenetic forms aneuploidy was detected. Aneuploidy was not described in *A. franciscana monica*, *A. persimilis*, *A. urmiana*, *A. sinica*, *A. tibetiana* (Abreu-Grobois, 1987).

All studied Artemia Russian populations (Mitrofanov et al., 1976; Boyko, Saukova, 2002; Boyko et al., 2002, 2005) were assigned to parthenogenetic forms.

Thus, there is possibility in presence of three, four and five haploid set and aneuploidy in studied Artemia populations from Russian reservoirs.

In order to study the features of Artemia chromosome set from lakes of the south of Western Siberia cytogenetic analysis of crustaceans was performed in follow lakes: Voskresenskoye, Sobachye, Bolshoye Medvezhye, Trebushinoye, Nevidim, Aktoban and Bolshoye Kureynoye (Kurgan region), Kulundinskoye and Bolshoye Yarovoye (Altai Territory), Ulzhay and Ebeyty (Omsk region), Okunevskoye (Tyumen region). A number of literary sources (Mitrofanov et al., 1976; Abatzopoulos et al., 1986) was used as comparative data.

Determination of chromosome number was performed in somatic cells. In preparations large number of prophase and interphase nuclei together with metaphase nuclei were found. Despite the fact that prophase is characterized by the beginning of spiralization, morphological features of chromosomes at this stage can not be detected. Therefore, only metaphase cells containing complete set of chromosomes in the field of view were analyzed (McGregor, Varly, 1986).

As a result of researches obtained data are presented in Tab. 16. At the study of each Artemia population on average 5 preparations of chromosomes, which were produced by the method provided E. Pilla (1992), were analyzed. Different number of metaphases with regular arrangement of chromosomes was found. Several metaphases (from 16 to 50) have been seen.

The most number of analyzed metaphases contained 42 chromosomes (Fig. 38).

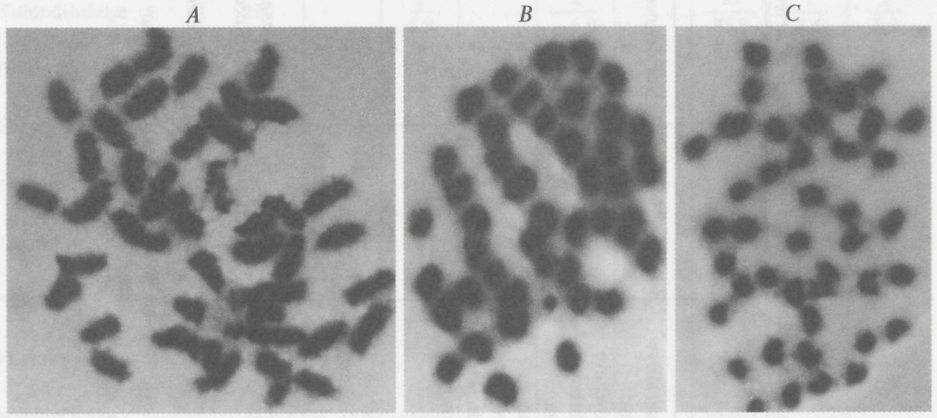


Fig. 38. Metaphase of Artemia.
A — Ebeyty; *B* — Bolshoye Kureynoye; *C* — Ulzhay ($2n = 42$).

Table 16. Cytological description of different Artemia populations

Lake	Reproductive model	Species	Number of chromo-centers	Number of cells	Level of ploidy	Modal number of chromo-somes	Number of nauplii	The number of samples	Number of prophase and meta-phase
Voskresenskoye	Parthenogenesis	Not defined	1–2	35	2n	42	15	5	30
Sobachye	»	»	1–2	41	2n	42	15	5	30
B. Medvezhye	»	»	1–2	16	2n	42	15	5	30
Trebushinoye	»	»	1–2	20	2n	42	15	5	30
Nevidim	»	»	1–2	32	2n	42	15	5	30
Aktoban	»	»	1–2	50	2n	42	15	5	30
B. Kureynoye	»	»	1–2	28	2n	42	15	5	30
Kulundinskoye	»	»	1–2	34	2n	42	15	5	30
B. Yarovoye	»	»	1–2	43	2n	42	15	5	30
Ulzhay	»	»	1–2	19	2n	42	15	5	30
Ebeyty	»	»	1–2	39	2n	42	15	5	30
Solenoye 18	»	»	1–2	29	2n	42	15	5	30
Bayan-Tuhum	Bisexual	»	1–2	28	2n	42	15	5	30
Karachi[1]	Parthenogenesis	»	—	28	2n	42	—	—	28
Tabechik[1]	Bisexual	»	—	88	2n	42	—	—	88
Urmia[2]	»	*A. urmiana*	1–2	50	2n	42	18	8	49
Citros[3]	Parthenogenesis	Not defined	—	—	2n	42	100	—	—
GSL[3]	Bisexual	*A. franciscana*	15.8 ± 0.99	—	—	84	—	—	—

Note. There are no data; references: [1] Mitrophanov et al., 1976; [2] Pilla, 1992; [3] Abatzopoulos et al., 1986.

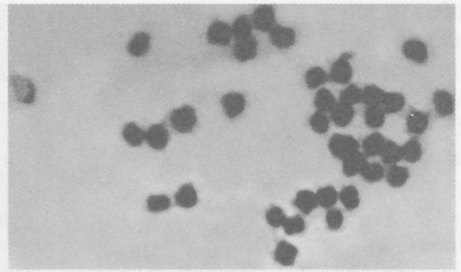


Fig. 39. Aneuploidy of Artemia from Bolshoye Yarovoye Lake ($n = 39$).

Thus, diploid number of chromosomes from studied Russian Artemia populations was equal to 42. In addition to normal set there were haploid cells and cells with chromosome complex which was not multiple to haploid numper (Fig. 39). Obtained data (Tab. 17) indicate the presence of variability in number of chromosomes and aneuploidy in Artemia, inhabiting in the south of Western Siberia.

The first stage of description of full chromosome set (karyotyping) is to codify chromosomes by sizes and shape in descending order as karyograms. The comparison of obtained kariograms allowed to reveal certain similarity in number and morphology of chromosomes from studied Artemia populations. Artemia karyogram from Bolshoye Yarovoye lake is presented in Fig. 40.

Table 17. **Ploidy level of Artemia of Siberian populations**

Lake	Number of metaphases	Number of metaphases with ploidy							
		20	21	39	40	41	42	43	44
B. Medvezhye	33	1/3	1/3			2/6.1	28/84.9	1/3	
Ulzhay	28					1/3.6	25/89.3	2/7.1	
B. Kureynoye	45	1/2.2	4/8.9				40/88.9		
Kulundinskoye	29		2/6.9		2/−6.9		22/75.9	1/3.4	2/6.9
B. Yarovoye	51			2/3.9	1/1.9		48/94.2		
Ebeyty	18					1/5.6	17/94.4		
Nevidim	21		1/4.7			1/4.7	19/90.6		
Trebushinoye	17						17/100		
Aktoban	19		1/5.3			2/10.5	16/84.2		
Filatovo	20					2/10	18/90		
Soleniy Kulat	24		1/4.2				23/95.8		

Note. Below line — quantity of metaphase in percentage, %; under line — in absolute number.

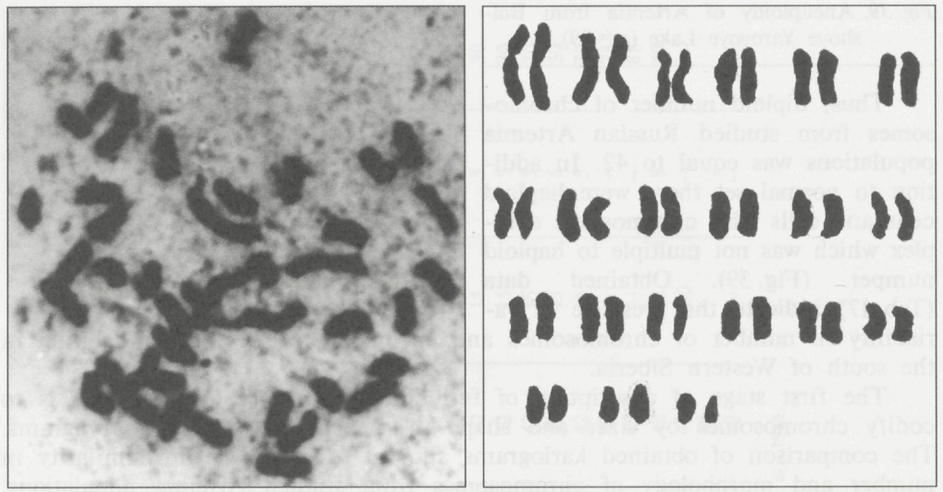


Fig. 40. Karyotype of Artemia from Bolshoye Yarovoye Lake.

Description of chromosomes was difficult by their small sizes and diffuse location of centromeres.

Systematization of Artemia chromosomes in shape and sizes allowed to make a karyogram. Autosomes (20 pairs) and sex chromosomes (1 pair) were divided such way that each chromosome corresponded to homologue. Analyzing the karyogram it can be noted the following. According to A. Levan's classification (1938) all chromosomes are telocentric. Each chromosome consists of two chromatids joined with centromere. In this case centromere is offset to one end of chromosome. At 42 chromosomes there are 42 shoulders. Centromere is not detectable visually. In parthenogenetic Artemia there is not any heteromorphicy of the first pair of chromosomes. The first and the largest chromosome pair defines Artemia sex (Stefani, 1963). Lack of selection stabilizing sex differences, apparently, led to disappearance in differences of sex chromosomes.

Measurement of absolute length of chromosomes was not made because it depends from techniques of making preparations and can vary even within individuals.

According to literature data (Stefani, 1963; Mitrophanov et al., 1976; Abatzopoulos et al., 1986; Abreu-Grobois, 1987), chromosomes refer to telocentric type. All authors indicate small sizes of chromosomes and diffuse centromeres as well as presence of chromocenters. Number of chromocenters varies from 1–2 (*A. urmiana*) to 17 (*A. franciscana*).

Comparison of karyotypes Artemia populations from lakes of Kurgan and Novosibirsk regions and Crimea (Mitrofanov et al., 1976) showed presence of significant similarity with studied Artemia populations. It connects not only with number of chromosomes ($2n = 42$) but also with type of chromosomes (telocentric).

Thus, on the basis of cytogenetic analysis of karyograms of Artemia nauplii from 12 Russian populations were composed and number of chromosomes was determined. Similarity in number, size and type of chromosomes were found. All studied populations are characterized by the same modal chromosome number (42); chromosomes are telocentric. Some Artemia nauplii had aneuploid cells. These data indicate the possibility of variation in number of chromosomes for Artemia from Siberian populations.

Relative suitability of polyploid and diploid individuals depends on environmental conditions. Diploids and polyploids respond to changes in environment in different ways. Polyploids have more advantages in compare with diploids in stressful situations. For example, when population is exposed to lethal temperatures in short period, polyploids are more likely to survive. Probably, in polyploid Artemia series of vital characteristics are developed which contribute to its adaptation to environment. Studied Artemia Russian populations are parthenogenetic and diploid. Likely Artemia evolution was such way that conditions for existence of crustaceans within the south of Western Siberia should be counted still far from being stress. On the other hand, the occurrence of rare males in parthenogenetic populations of Russian Artemia can be evidence in some instability of conditions for existence and possible deterioration of conditions.

3.3. DNA analysis

Almost every species of animals is divided into more or less number of completely or partially isolated populations — geographical subspecies, races and smaller groups. The genus *Artemia* in this regard is not exception. Currently large amount of data in sites of restriction and DNA sequences has been got. These data can be used in population-genetic studies in order to establish sibling relationships between different Artemia locations. These studies are based on the use of modern methods of molecular genetics. The aim of taxonomy is to combine organisms in convenient number of groups having the same features; it allows to classify species. In evolutionary studies such classification gives possibility to construct phylogeny. This kind of construction can reveal whether there is a relationship between observed phylogenetic relationships of species and evolutionary forces (Weir, 1995). Obtained results help to answer a lot of questions concerning phylogeny, systematics and differentiation of the genus *Artemia*. Despite the rapid development of methods for molecular genetic analysis, a point in establishment of relationships between different Artemia populations has not come yet.

Currently, differentiation of the genus *Artemia* is solved with help of whole arsenal of methods and techniques, which very diversity demonstrates the importance of this problem both in point of view fundamental and applied science. Indeed, data on population structure are very important in theoretical constructs related to phylogeny of species, formation of their present areas. As well as they are the most important source of information dealing with rational exploitation of biological resources.

In addition to self-evident adverse impacts such as pollution of environment, destruction of habitat for hydrocoles, at least, another factor is responsible for the decline in biodiversity — unsustainable economic activity ignoring genetic differentiation of species and structure of species genofond. It is total genetic information, which passes from parents to offsprings in every generation and determines important properties such as amount, productivity, speed of growth and development, duration of individual life, resistance to environmental stress (Altukhov et al., 2004).

On the other hand, the vast diversity of existing approaches to study population differentiation indicates the absence of universal method which could allow to establish population composition of species more accurately. First of all, this is due to plasticity of studied biological structures, as well as limitations as for research methods and for ways of interpreting obtained results. After that there is necessary for comprehensive analysis of population structure of the genus *Artemia*, comparing the results of use of independent methods in order to obtain sufficiently complete and adequate picture of differentiation.

Genetic techniques for studying of species population structure are similar to morphological methods because they have meaning only if observed differences in signs to some extent are determined genetically. The principal difference is in fact that within population genetic studies features, directly reflected the structure of genome, are used. In this structure, first of all, it should be expected the effects of full or partial reproductive isolation.

Genetic methods are divided into two groups: methods of biochemical genetics and molecular genetics techniques. Until recently methods of biochemical genetics had the greatest development.

Now together with study of protein polymorphism in population-genetic studies analysis of variability of nuclear and mitochondrial DNA (mtDNA) is used widely. Methods of DNA analysis without doubt provide much more complete picture of genetic variability of populations, because nucleotide sequences coding proteins constitute only a small part of genome, as electrophoresis method allows to detect less 30 % amino acid substitutions in composition of protein molecules (Hallerman, Beckman, 1988). Since predominant part of genome is not involved in any known and important functions, corresponding sections of noncoding DNA detect levels of polymorphism, which are greatly higher then all known about protein polymorphism (Altukhov et al., 2004).

In many cases, DNA structure analysis helps to find genetic interspecies or interpopulational differences which are not recognized by electrophoresis of proteins (Smith, McVeagh, 2000). Despite that fact many scientifics have an opinion that polymorphism of proteins and DNA supplement each other, depending on the task.

Very important method used widely in study of DNA polymorphism is a method of polymerase chain reaction (PCR). It allows to amplify desired nucleotide sequences from small amounts of DNA animal and vegetable origin quickly and easily. Identification with PCR is carried out on the basis of presence or absence particular DNA fragment. All methods of DNA identification in electrophoresis create character pattern of bands (they generate pattern),

showing variability of genome. This method allows to study genetic variability of organisms in shorter time and increases number of solved biological problems, including:

— the establishment of features of differentiation;

— analysis of genetic differences between populations and their adaptive nature;

— analysis of current state of resources and their use.

Despite of obvious advantages of genetic methods over others in study of species population structure, the nature of subspecies differentiation and phylogenetic relationships some highly organized objects are not fully clear. There are many reasons for that. The lack of universal methodological base and inconsistency in interpretation of genetic data by different researchers are only some of them.

Genetic structure of Artemia populations is formed under pressure of biological characteristics of object and environment. The formation of genetic structure of natural Artemia populations under influence of various factors does not always lead to impoverishment of genefond. As a result it can also be increased in variability and thus increasing in divergence between the existing locallities.

At the moment there is no national literature to assess the genetic differences between Artemia populations. The leading role in this matter belongs to foreign scientifics (Sun et al., 1999; Abatzopoulos et al., 2002; Xiaomei et al., 2002; et al.). Necessity of this study is to determine the nature and direction of changes in Russian Artemia populations, as well as identifying specific molecular markers. It will allow not only to identify the current condition of populations, but also to possibility to design of their changes in future.

Genetic certification of existing Artemia populations can be made by method of DNA fingerprinting combined with monitoring of genomic polymorphism with help of one of existing instrumental methods, including polymerase chain reaction and subsequent automatic separation of amplificators in capillar electrophoresis. In some cases the definition of primary nucleotide sequence or sequencing of cloned fragments is significant. At sufficiently widely scope of population all of them will be genetically tagged. The possibility of objective estimate of such important parameter as relationship will be enable.

The aim of these researches is identification of Russian Artemia populations as a part of global database of DNA-fingerprinting. This work is devoted to experimental development of molecular genetic testing of various Artemia populations. The researches included follow tasks:

— to examine molecular markers and polymorphism of nuclear and mitochondrial genomes;

— to conduct analysis of cytochrome oxidase I (COI) mitochondrial DNA;

— to conduct comparative genetic analysis of domestic and foreign Artemia populations.

Studies have been conducted in laboratory of Aquaculture and Artemia Research Center at Ghent University (Belgium) in collaboration with belgian scientists on the basis of CLO-Sea Fisheries Department, as well as on the

basis of the Laboratory of Genetic Identification VNIRO (Moscow) with participation of colleges V.A. Barmintsev and A.A. Volkov.

The objects for researches were Artemia cysts collected in natural salt reservoirs of Russia (Siberia) and Mongolia, as well as cysts well-known species and undentified populations all over the world, which were suggested politely by the staff of Artemia Reference Center (Ghent, Belgium). Experiments to determine the extent of distinctions between different Artemia populations were carried out in three different ways:

— analysis of well-known fragments mtDNA (RFLP — PCR);
— analysis of unknown genomic DNA fragments (RAPD — PCR);
— sequencing of cytochrome oxidase I (COI) mtDNA.

3.3.1. Restriction fragment length polymorphism (RFLP)

Methods based on the use of PCR-analysis and used for molecular genetic identification of aquatic organisms can be divided into two groups. One of them involves specific amplification and analysis of DNA sequences (Altukhov et al., 2004).

The advantage of specific amplification DNA is that this method is less sensitive to differences in reaction conditions, and it allows to obtain reproducible patterns of DNA.

The method consists in amplification of specific DNA fragment containing analyzed point mutation with followed digestion of that fragment by appropriate restrictive endonuclease. Analyzing the length of fragments (RFLP) conclusion about the absence or presence of point mutation, as well as homozygous or heterozygous for this allele individual was given (Zinovjeva et al., 2002).

In case when degraded DNA should be investigated, PCR is often carried out on mtDNA because of its significantly higher making copies relatively sequences of nuclear DNA. Furthermore, it is assumed that mtDNA as circular molecule has higher resistance to degradation. For fish species identification mtDNA is used successfully: mainly gene cytochrome b and less — D-loop (Bossier, 1999). The choice of primers used for amplification of fragments of gene cytochrome b, depends on belonging to systematic group and degree of DNA degradation. However, mtDNA is conservative enough and, as a role, due to this fact it is impossible to conduct intrapopulation identification.

This technique has been tested on small material consisting of 10 Artemia populations from the lakes of south of Western Siberia: Kulundinskoye and Bolshoye Yarovoye from Altai Territory; Filatovo, Sobachye, Bolshoye Medvezhye, Trebushinoye, Nevidim and Bolshoye Kureynoye from Kurgan region; Ulzhay and Ebeyty from Omsk region.

None whole genome but only a small part of it was examined. MtDNA was used as differentiating vector, which was represented by only one circular molecule with length 15 822 nuclear (base) pairs (bp) (Fig. 41). Composition of genes of this molecule is universal for all animals (Xiaomei et al., 2002). 13 genes of mtDNA from 38 coding proteins, 22 genes coding tRNA, one gene is non-coding and the most variable, two genes coding synthesis of ribosomal

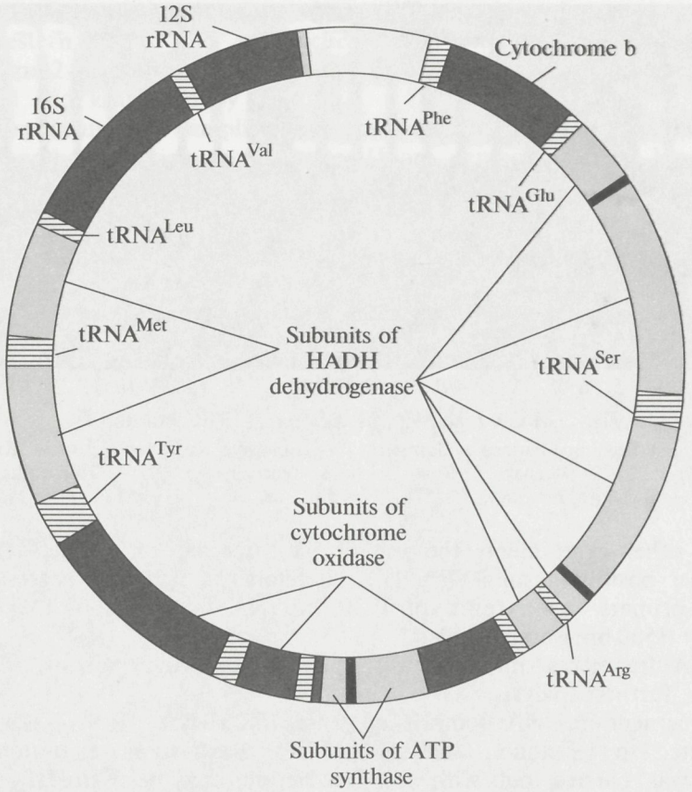


Fig. 41. Scheme of mtDNA (Xiaomei Wang et al., 2002).

RNA (rRNA). Taxonomists are interested mainly by these two genes, which are the most conservative. Many researchers use genes coding rRNA synthesis to determine the phylogenetic systematics.

At the first stage fragment of mtDNA comprising two rRNA genes was isolated and amplified. Polymerase chain reaction was carried out with help of three pairs of primers (12S-R and 16S-R, 12S-SP and 16S-SP, 12S-RL and 16S-FL), and DNA — polymerase.

PCR reaction of Artemia DNA from lake Sobachye with all three pairs of primers was not effective (Fig. 42). This is probably due to the fact that primers did not recognize parts of Artemia DNA of the lake. To make a decision of this question it is necessary to expand the range of primers.

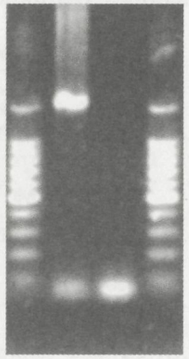
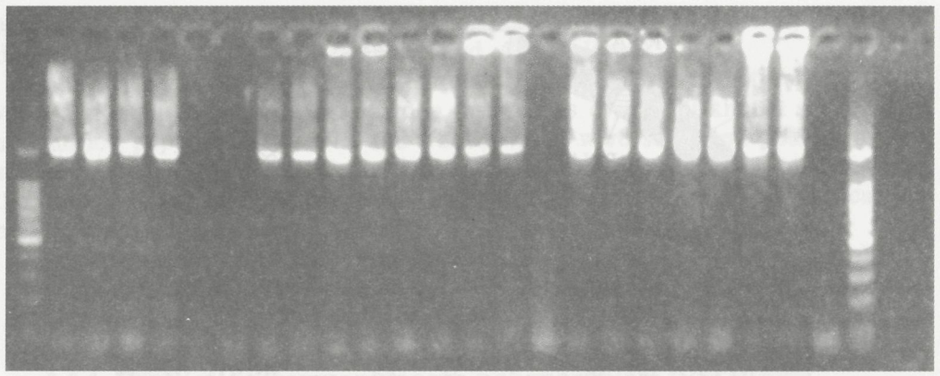


Fig. 42. PCR-reaction with primers 12S-R, 16S-R.
Lanes: *1* — *A. franciscana*; *2* — Sobachye Lake.



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Fig. 43. PCR-reaction with primers 12S-R and 16S-F.

On lines Artemia from populations of lakes: *1, 2* — Bolshoye Kureynoye; *3, 4* — Kulundinskoye; *5, 6* — Sobachye; *7, 8* — Ulzhay; *9, 10* — Bolshoye Medvezhye; *11, 12* — Trebushinoye; *13, 14* — Filatovo; *15* — Bolshoye Yarovoye; *16, 17* — Nevidim; *18, 19* — Ebeyty; *20, 21* — *A. franciscana.*

In all other experiments the use of the first pair of primers (12S-R and 16S-F) gave positive results (Fig. 43). Therefore, it was not necessary to use remaining primers. As a result of PCR mtDNA fragments of the length approximately 1500 bp were received.

MtDNA fragments amplified with help of the first pair of primers were involved in further analysis.

The fragment mtDNA comprising genes 16S rRNA, tRNA-Val, 12S rRNA was subjected to restriction analysis (RFLP). Restriction separation of DNA fragments was carried out with five restriction enzymes: *Hae*III, *Taq*I, *Tsp*, *Hpa*II, *Nde*II (Tab. 18). Restriction enzymes or endonucleases conduct DNA cutting. They react only with specific, consisting of 4–6 base pairs demethylated DNA segments — recognition sites. Under processing DNA by endonuclease fragments with so-called "sticky ends" are formed because after cutting double-stranded DNA one of the chains is longer than another in some nucleotides (Altukhov et al., 2004).

Table 18. **Results of RLFP**

Lake and species	Restriction enzyme				
	Tsp 5091	*Hpa*II	*Taq*I	*Hae*III	*Nde*II
Filatovo	–	+	+	+	+
B. Kureynoye	–	+	+	+	+
Kulundinskoye	–	+	+	+	+
Sobachye	–	–	–	–	–
Ulzhay	–	+	+	+	+
B. Medvezhye	–	+	+	+	+
Trebushinoye	–	+	+	–	+
Ebeyty	–	+	+	+	+
B. Yarovoye	–	+	+	+	+
Nevidim	–	+	+	+	+
A. franciscana N 1286	–	+	+	+	+

Analysis of restriction products from different Artemia populations of the south of Western Siberia and *A. franciscana* was conducted by gel-electrophoresis method in 2 % agarose. The mixture of DNA fragments were separated in electric field and visualized by staining.

RFLP spectrums of amplification products of mtDNA studied Artemia populations with restriction enzyme *Hae*III are demonstrated in Fig. 44. Identification of phoregramm showed the presence of two DNA fragments after restriction. In compare with Lader (the standard used to determine number of nucleotyde pairs in DNA fragments) dimensions of two obtained DNA frag-

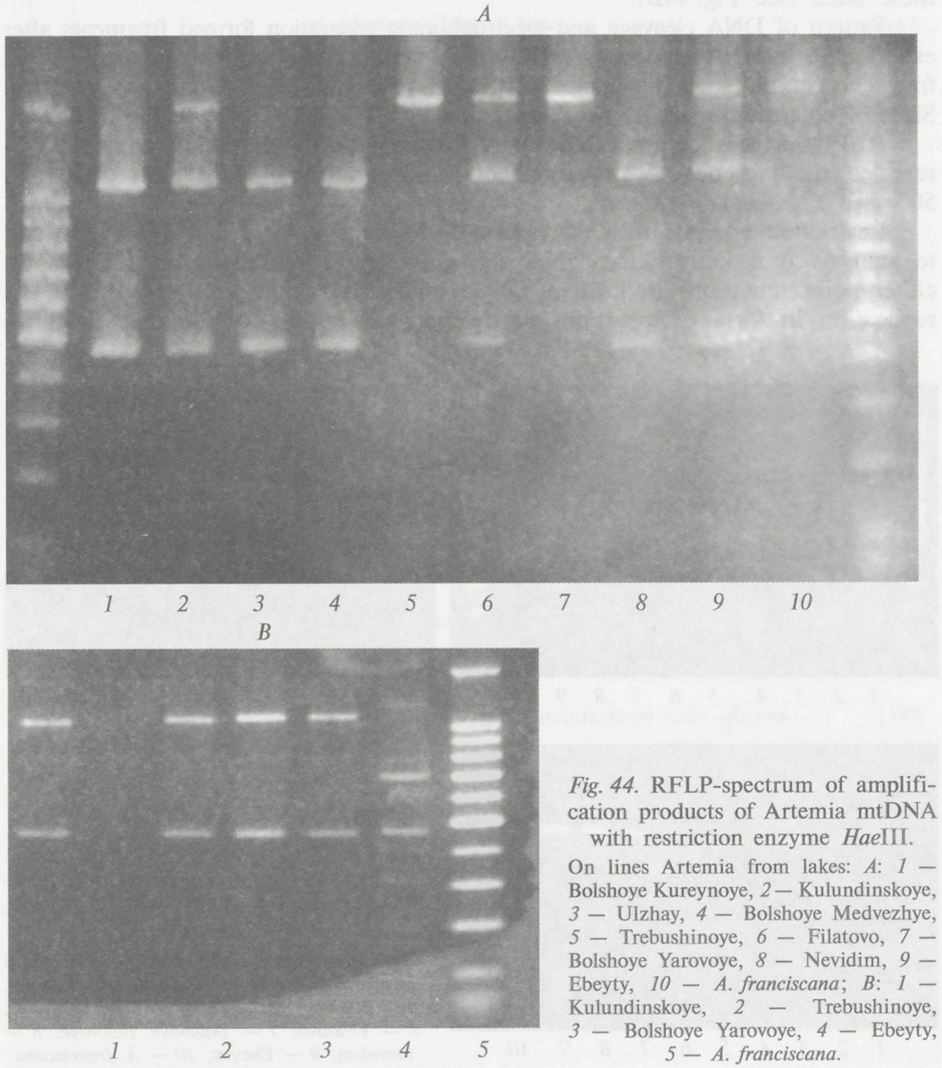


Fig. 44. RFLP-spectrum of amplification products of Artemia mtDNA with restriction enzyme *Hae*III.

On lines Artemia from lakes: *A*: *1* — Bolshoye Kureynoye, *2* — Kulundinskoye, *3* — Ulzhay, *4* — Bolshoye Medvezhye, *5* — Trebushinoye, *6* — Filatovo, *7* — Bolshoye Yarovoye, *8* — Nevidim, *9* — Ebeyty, *10* — *A. franciscana*; *B*: *1* — Kulundinskoye, *2* — Trebushinoye, *3* — Bolshoye Yarovoye, *4* — Ebeyty, *5* — *A. franciscana.*

ments correspond to nearly 1000 and 500 bp. Thus, the basic rule of RLFP — PCR analysis about coincidence sizes of DNA fragments after PCR and restriction was received because PCR fragment was equal 1500 bp.

In general, restriction analysis with help of enzyme *Hae*III PCR-products of Artemia from investigated lakes showed presence of two restriction fragments, except the samples from lakes Trebushinoye and Bolshoye Yarovoye. Restriction of fragment Artemia DNA from the lakes Kulundinskoye and Ebeyty was with release not two, but three fragments. The length of these segments does not match 1500 bp. Therefore, it is necessary to repeat analysis of these lakes (see Fig. 44*B*).

Pattern of DNA cleavage and electrophoretic separation formed fragments after exposure to mtDNA enzyme *Hpa*II is presented in Fig. 45*A*. The presence of six fragments in all studied samples of Russian Artemia populations was revealed. Sizes of obtained fragments were approximately 500, 400, 300, 90, 60, 50 bp.

RLFP analysis of amplified DNA fragments with restriction enzyme *Taq*I revealed the presence of two fragments with number of base pairs 1000 and 500 (see Fig. 45*B*).

Restriction analysis with enzymes *Nde*II (see Fig. 45*C*) and *Tsp* is difficult to analyze. It is known that DNA polymorphism is caused by several reasons: either point mutations in form of single nucleotide changes or errors in DNA replication in form of insertions or deletions from one to hundreds or thou-

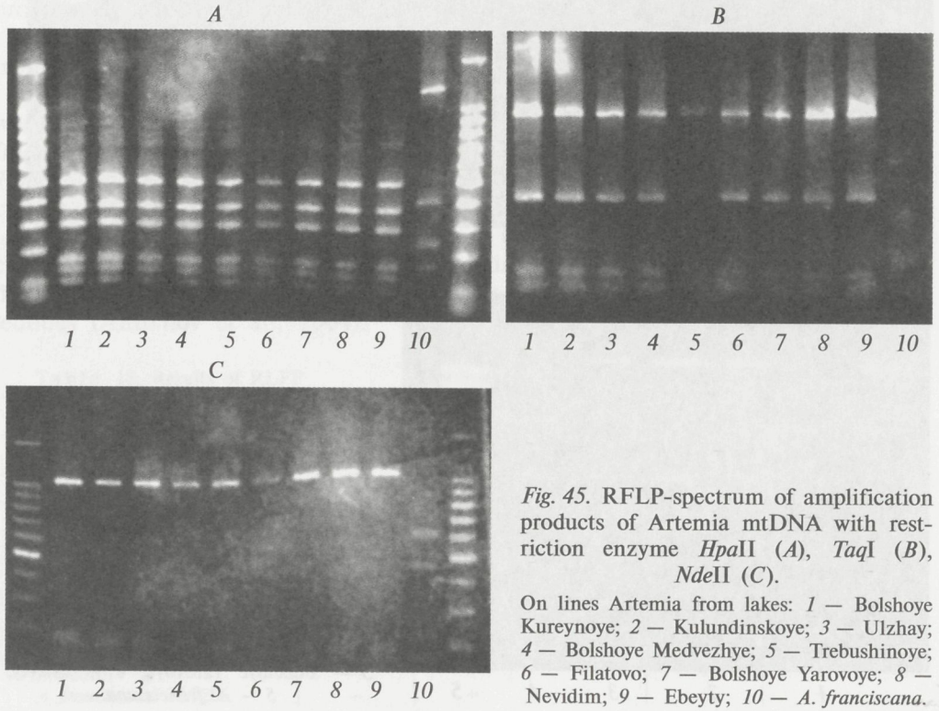


Fig. 45. RFLP-spectrum of amplification products of Artemia mtDNA with restriction enzyme *Hpa*II (*A*), *Taq*I (*B*), *Nde*II (*C*).

On lines Artemia from lakes: *1* — Bolshoye Kureynoye; *2* — Kulundinskoye; *3* — Ulzhay; *4* — Bolshoye Medvezhye; *5* — Trebushinoye; *6* — Filatovo; *7* — Bolshoye Yarovoye; *8* — Nevidim; *9* — Ebeyty; *10* — *A. franciscana*.

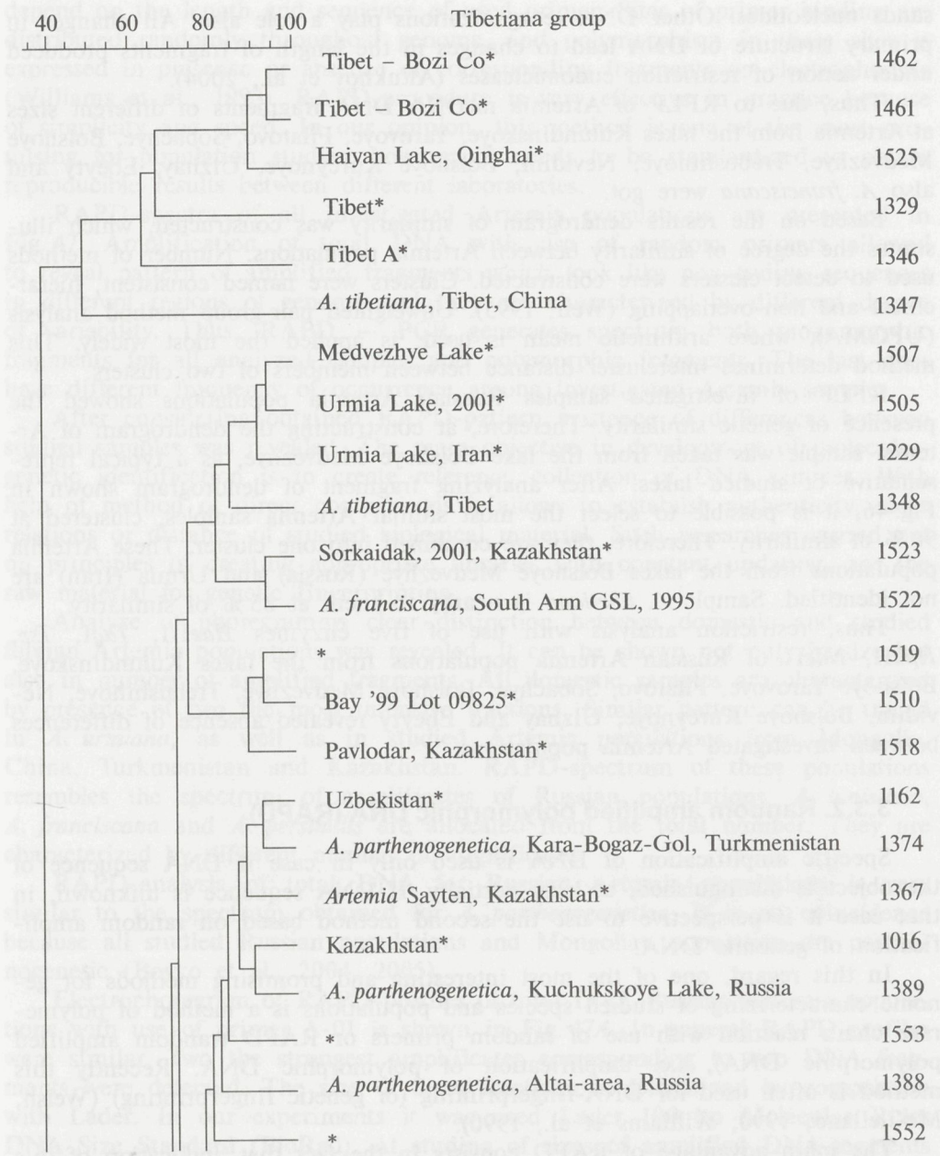


Fig. 46. UPGMA-dendrogram of similarity of some Russian Artemia population in-group of the most similar groups and species of Artemia (Catania et al., 2002).

Note. * Unidentified.

sands nucleotides. Other DNA reorganizations play a role also. All changes in primary structure of DNA lead to changes in the length of fragments produced under action of restriction endonucleases (Altukhov et al., 2004).

Thus, due to RFLP of Artemia mtDNA DNA fragments of different sizes at Artemia from the lakes Kulundinskoye, Yarovoye, Filatovo, Sobachye, Bolshoye Medvezhye, Trebushinoye, Nevidim, Bolshoye Kureynoye, Ulzhay, Ebeyty and also *A. franciscana* were got.

Based on the results dendrogram of similarity was constructed, which illustrates the degree of similarity between Artemia populations. Number of methods used to detect clusters were constructed. Clusters were named consistent, hierarchical and non-overlapping (Weir, 1995). Unweighted pair-group method analysis (UPGMA), where arithmetic mean is used, is applied the most widely. This method determines intercluster distance between members of two clusters.

RFLP of investigated samples Russian Artemia populations showed the presence of genetic similarity. Therefore, at constructing the dendrogram of Artemia sample was taken from the lake Bolshoye Medvezhye, as a typical representative of studied lakes. After analyzing fragment of dendrogram shown in Fig. 46, it is possible to select the most similar Artemia samples, clustered at 90 % of similarity. Therefore, they are combined into one cluster. These Artemia populations from the lakes Bolshoye Medvezhye (Russia) and Urmia (Iran) are not identified. Sample *A. tibetiana* is nearby to them at 85 % of similarity.

Thus, restriction analysis with use of five enzymes *Hae*III, *Taq*I, *Tsp*, *Hpa*II, *Nde*II of Russian Artemia populations from the lakes Kulundinskoye, Bolshoye Yarovoye, Filatovo, Sobachye, Bolshoye Medvezhye, Trebushinoye, Nevidim, Bolshoye Kureynoye, Ulzhay and Ebeyty revealed absence of differences between investigated Artemia populations.

3.3.2. Random amplified polymorphic DNA (RAPD)

Specific amplification of DNA is used only in case if DNA sequence of the object is distinguished, at least partially. If DNA sequence is unknown, in that case it is perspective to use the second method based on random amplification of genomic DNA.

In this regard, one of the most interesting and promising methods for genome characterizing of studied species and populations is a method of polymerase chain reaction with use of random primers or RAPD (random amplified polymorphic DNA), i.e. amplification of polymorphic DNA. Recently this method is often used for DNA-fingerprinting (or genetic fingerprinting) (Welsh, McClelland, 1990; Williams et al., 1990).

The main advantage of RAPD consists in the fact that application of this method does not require prior knowledge about DNA sequence. RAPD-amplification is performed with short primers (10–20 bp) with sequences selected randomly (Altukhov et al., 2004). It allows to conduct synthesis till several tens of DNA fragments in each reaction. Localization of amplified sequences in genome is unknown, however, the resulting set of fragments (patterns on electrophoresis) is typical for each sample. Number and size of amplified fragments

depend on the length and sequence of used primer. Sites of primer binding are distributed randomly throughout genome, and polymorphism in these sites is expressed in presence or absence of corresponding fragments on electrophoresis (Williams et al., 1993). RAPD-procedure is very effective in practice because of simplicity and speed. In our opinion, this method is one of the most promising for population studies, however, it needs to be standardized to obtain reproducible results between different laboratories.

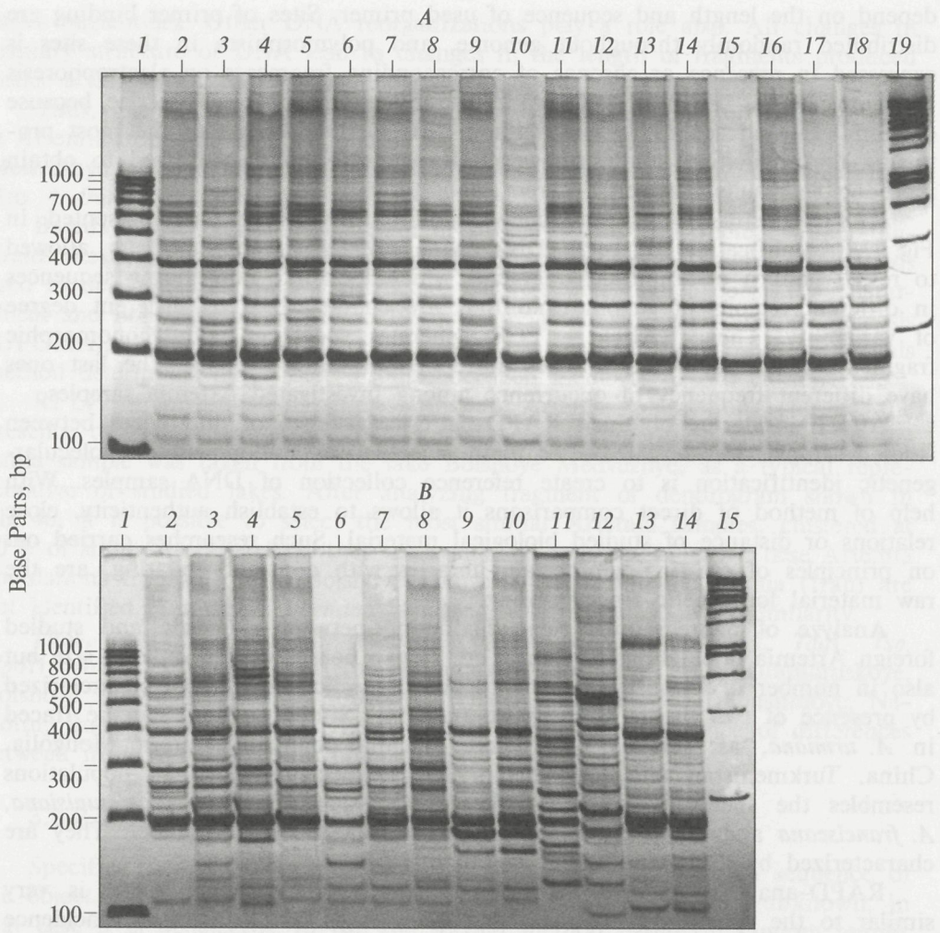
RAPD-spectra of all investigated Artemia populations are presented in Fig. 47. Amplification of total DNA with use of random primers allowed to reveal pattern of amplified fragments which look like non-coding sequences in different regions of genome and they are characterized by different degree of variability. Thus, RAPD — PCR generates spectrum both monomorphic fragments for all analyzed samples and polymorphic fragments. The last ones have different frequency of occurrence among investigated Artemia samples.

After considering obtained RAPD-pattern existence of differences between studied samples was revealed. The main objective in development of molecular-genetic identification is to create reference collection of DNA samples. With help of method of direct comparisons it allows to establish authenticity, close relations or distance of studied biological material. Such researches carried out on principles of creating appropriate libraries with constant updating, are the raw material for genetic fingerprinting.

Analyze of phoregramms clear distinction between domestic and studied foreign Artemia populations was revealed. It can be shown not only in size but also in number of amplified fragments. All domestic samples are characterized by presence of two the most intensive fractions. Similar pattern can be traced in *A. urmiana*, as well as in studied Artemia populations from Mongolia, China, Turkmenistan and Kazakhstan. RAPD-spectrum of these populations resembles the spectrum of amplificates of Russian populations. *A. tunisiana*, *A. franciscana* and *A. persimilis* are allocated from the total number. They are characterized by different number of amplificates.

RAPD-analysis of total DNA for Russian Artemia populations is very similar to the spectrum obtained for *A. parthenogenetica*. It is no coincidence because all studied Russian populations and Mongolian population are parthenogenetic (Boyko et al., 2004, 2005).

Electrophoregram of RAPD-profiles of total DNA Russian Artemia populations with use of primer A-01 is shown in Fig. 47*A*. In general RAPD-profiles were similar. Two the strongest amplificates corresponding to two DNA fragments were detected. The size of these fractions is determined by comparison with Lader. In our experiments it was used Lader 100 bp Molecular Ruler DNA Size Standard (BioRad). At studing of sizes of amplified DNA-segments with primer selected randomly the presence of two fragments with number of base pairs 400 and 200 was revealed. In electrophoregram there were also weaker bands. Their number varies. Among them fractions corresponding to sizes 300 and 260 bp in the middle part of profile are prominent most of all. These four major amplificates were used subsequently for comparative analysis with other studied populations.



Populations from the lakes Okunevskoye, Sobachye, Voskresenskoye and Trebushinoye, besides of *A. urmiana*, *A. tunisiana*, *A. franciscana* and *A. sinica* are presented in Fig. 47*B*. On electrophoregram similarity between parthenogenetic Artemia populations from Siberian lakes was clearly evident. However, Artemia of the lake Voskresenskoye is different from the total number of populations, here there is a fragment with size 650 bp. There is some similarity of obtained profiles Russian Artemia populations with *A. urmiana*, *A. tibetiana* and *A. sinica*. This similarity reflected mainly in the presence of amplificates with sizes 300 and 400 bp for all these samples. *A. urmiana*, *A. tibetiana A. sinica* are characterized by the presence of additional bands which are not typical for Russian Artemia. In both samples *A. urmiana* there is a band with size slightly less than 400 bp. In both samples *A. tibetiana* there is an additional band corresponding to 180 bp of RAPD-spectrum.

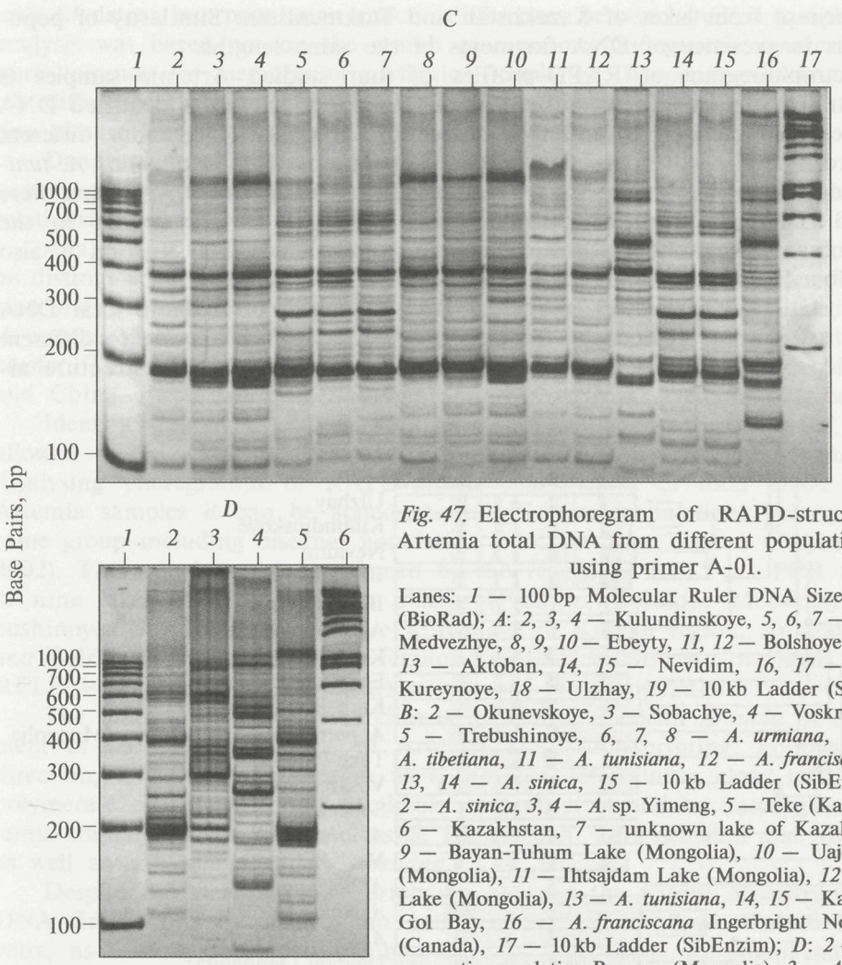


Fig. 47. Electrophoregram of RAPD-structures of Artemia total DNA from different populations with using primer A-01.

Lanes: *1* — 100 bp Molecular Ruler DNA Size Standard (BioRad); *A*: *2*, *3*, *4* — Kulundinskoye, *5*, *6*, *7* — Bolshoye Medvezhye, *8*, *9*, *10* — Ebeyty, *11*, *12* — Bolshoye Yarovoye, *13* — Aktoban, *14*, *15* — Nevidim, *16*, *17* — Bolshoye Kureynoye, *18* — Ulzhay, *19* — 10 kb Ladder (SibEnzim); *B*: *2* — Okunevskoye, *3* — Sobachye, *4* — Voskresenskoye, *5* — Trebushinoye, *6*, *7*, *8* — *A. urmiana*, *9*, *10* — *A. tibetiana*, *11* — *A. tunisiana*, *12* — *A. franciscana SFB*, *13*, *14* — *A. sinica*, *15* — 10 kb Ladder (SibEnzim); *C*: *2* — *A. sinica*, *3*, *4* — *A.* sp. Yimeng, *5* — Teke (Kazakhstan), *6* — Kazakhstan, *7* — unknown lake of Kazakhstan, *8*, *9* — Bayan-Tuhum Lake (Mongolia), *10* — Uajdam Lake (Mongolia), *11* — Ihtsajdam Lake (Mongolia), *12* — Tuhum Lake (Mongolia), *13* — *A. tunisiana*, *14*, *15* — Kara-Bogas-Gol Bay, *16* — *A. franciscana* Ingerbright North Lake (Canada), *17* — 10 kb Ladder (SibEnzim); *D*: *2* — parthenogenetic population Bameng (Mongolia), *3* — *A. tunisiana* Wadi Nartrum (Egypt), *4* — *A. persimilis* (Argentina), *5* — *A. sinica* Haolebaoji (China), *6* — 10 kb Ladder (SibEnzim).

A. sinica is different from Russian populations less marked fragments in the middle of the Figure. Profiles *A. franciscana* and *A. tunisiana* are different from the others. Significant similarity RAPD-profiles of studied populations from Asian continent was marked.

Next electrophoregram is presented by samples from China, Kazakhstan, Mongolia, Turkmenistan and Canada (see Fig. 47*C*). Analysis of RAPD-profiles showed a clear difference between the samples from the Mediterranean and America: *A. tunisiana* and *A. franciscana*, respectively. It should be noted significant similarity between some populations from the Asian continent, such as

brine shrimps from lakes of Kazakhstan and Turkmenistan. Similarity of populations is in presence of DNA fragments of the same lengths.

Electrophoregram of RAPD-profiles of four studied Artemia samples is demonstrated in Fig. 47*D*. Amplification of total DNA has been identified DNA sequences characterized by different degree of variability. Thus, four different DNA-profiles of parthenogenetic Artemia populations from Mongolia, *A. tunisiana* from Egypt, *A. sinica* from China and *A. persimilis* from Argentina were obtained. DNA-spectrum of parthenogenetic Artemia is very similar to the nature of amplification of Russian Artemia populations. This situation is also proper for *A. sinica*.

For statistical evaluation conducted RAPD-analysis of Artemia total DNA allowed to allocate polymorphic fragments in 31 samples belonging to different Artemia populations (Fig. 48). In this case, the analysis of DNA structure al-

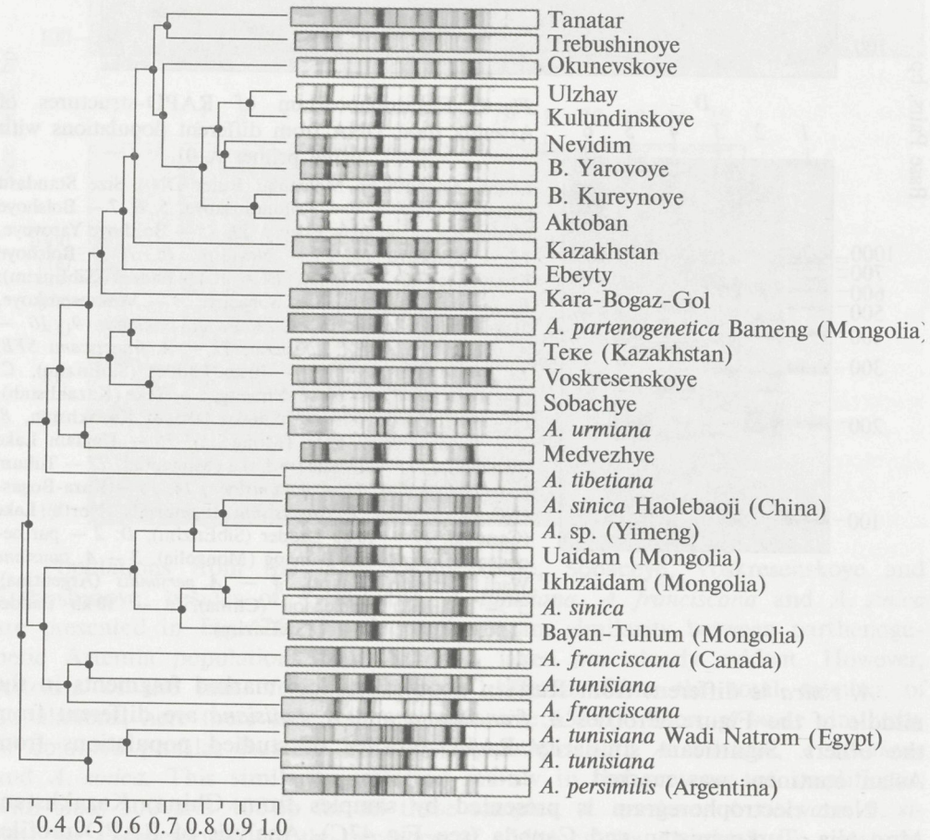


Fig. 48. Dendrogram of genetic similarity of RAPD-structures DNA with using primer A-01 of analyzed Artemia shrimps constructed on the basis of the designed factors of distances on Dice with help of algorithm cluster analysis UPGMA (tolerance 20).

lows to detect interpopulation genetic differences between studied samples. The analysis was based not on the search of monomorphic genetic markers which were common for members of particular population. It was important to identify differences between populations with help of marked fragments. The resulting picture was quite variable.

Dendrogram of similarity was constructed based on the analysis of frequency of occurrence of obtained profiles. Dendrogram demonstrates the exact relationships in studied populations more clearly.

Analyzing the clustering, three groups of investigated *Artemia* samples can be distinguished. Russian populations together with brine shrimps from Kazakhstan and Turkmenistan were combined into the first largest cluster. *A. tibetiana*, *A. urmiana* and parthenogenetic population from Mongolia were also in the first cluster. The second cluster was formed by Artemia populations from Mongolia and China. *A. persimilis*, *A. tunisiana* and *A. franciscana* were in outgroup.

Identification by RAPD — PCR with help of direct comparison of profiles allowed to set close relations and distant of different Artemia populations. Analysing phoregramm of RAPD-profile amplificates of total DNA studied Artemia samples it can be stated that all Russian populations belong to the same group including bisexual population from the lake Tanatar (Boyko et al., 2002). This conclusion is confirmed by the results of RFLP — PCR analysis of nine lakes south of Western Siberia (Filatovo, Bolshoye Medvezhye, Trebushinoye, Nevidim and Bolshoye Kureynoye in Kurgan region; Kulundinskoye and Bolshoye Yarovoye in Altai Territory; Ulzhay and Ebeyty in Omsk region). RFLP — PCR analysis revealed similarity of these populations.

The main aim of our researches is to identify Russian *Artemia* in development of the global database of Artemia DNA-fingerprinting. Following this direction, it needs to note that as a tool for determining close relationships polymerase chain reaction is a reliable method. It should be noted genetic Artemia similarity from lakes of Russia, Kazakhstan, Turkmenistan and Mongolia, as well as *A. urmiana* and *A. tibetiana*.

Despite the lack of clear correlation between the nature of distribution of DNA fingerprints in dendrogram and geographical location of studied reservoirs, as well as species belonging, there is a tendency to group individuals united by geographical factor. It points to require for more detailed analysis, when there is a high probability of finding a marker or group of markers associated with the presence of any feature which is manifested directly or indirectly in each population.

3.3.3. Polymorphism of DNA fragments amplified with help of random primers (A-01, A-09, A-14)

In order to identify the most appropriate primer for RAPD Artemia their range was expanded. The analysis of RAPD-spectrum based on presence or absence of individual fractions in each spectrum revealed the existence of differences between studied Artemia samples. Thus, the degree of distant of investigated biological material was established by method of direct comparisons.

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RAPD-analysis of Artemia total DNA allowed to allocate polymorphic fragments of representatives from 16 samples belonging to different populations for statistical evaluation (Fig. 49). In this case, the analysis of DNA structure has revealed interpopulation genetic differences between researched samples.

At applying of three primers difficult RAPD profiles were obtained. Each sample contains a lot of bands, their analysis is complicated by large number of weak patterns. During analysis of all phoregrams clear distinction between domestic and foreign Artemia populations was revealed. It happens not only in sizes but also in number of amplified fragments.

Under using primer A-01 profiles of Russian Artemia populations contain about seven most intense fractions. A similar pattern detects in *A. urmiana*, Artemia from Mongolia, China, Turkmenistan and Kazakhstan. RAPD-spectrum of these populations resembles the spectrum of amplificates of Russian populations. *A. tunisiana*, *A. franciscana* and *A. persimilis* are allocated from total number. They are characterized by different pattern. RAPD-profiles of Russian Artemia populations from the lakes Svatikovo, Tanatar, Bolshoye Medvezhye, Ebeyty, Bolshoye Yarovoye, Trebushinoye were similar.

RAPD-spectrum of 16 Artemia samples with use of primer A-09 revealed similarity of all Russian samples, except Artemia from lake Bolshoye Yarovoye. Profile of this sample stands out from the total number. Also there are contrasts of patterns *A. tunisiana*, *A. franciscana* and *A. persimilis*.

RAPD-profiles with use of primer A-14 were quite clear. All samples contained more than five bands. All samples in the area of short lengths (211–247 bp) had bands, except for *A. tunisiana*, *A. franciscana* and *A. persimilis*. Additional fragments appeared in the area 339 bp in *Artemia* from the lakes Bolshoye Yarovoye, Svatikovo, Teke (Kazakhstan), Bayan-Tuhum (Mongolia), *A. tibetiana*, *A. sinica*. In the area 448 bp there were bands in all samples, except for *A. sinica*, none identified bisexual *Artemia* population from the lake Svatikovo, *A. tunisiana*, *A. franciscana* and *A. persimilis*. The spectrum of the longest segments was more variable. In this area there were lots of weak bands which were difficult for analyzing.

Thus, it is possible to note some similarity of profiles for Russian Artemia populations, *A. urmiana*, *A. tibetiana* and *A. sinica*. Similarity was mainly in the presence of amplificates of certain dimensions. Significant similarity of profiles of studied populations in Asian continent was marked.

Profiles *A. franciscana*, *A. persimilis* and *A. tunisiana* were different from others.

Due to analysis of frequency of occurrence of selected fragments UPGMA-dendrograms based on obtained profiles were constructed. They demonstrate close relationships between populations more clearly.

Similarity dendrograms were shown in Fig. 50.

Analyzing the clustering, it is possible to discover three clusters of studied Artemia samples (see Fig. 50*A*). The first cluster consists two subclusters combined on the level of index is similarity which was equal to 0.60. One subcluster consisted of bisexual populations from the lakes Svatikovo (Tuva) and Tanatar (Altai), *A. sinica* (China), as well as population from lake Bayan-Tuhum

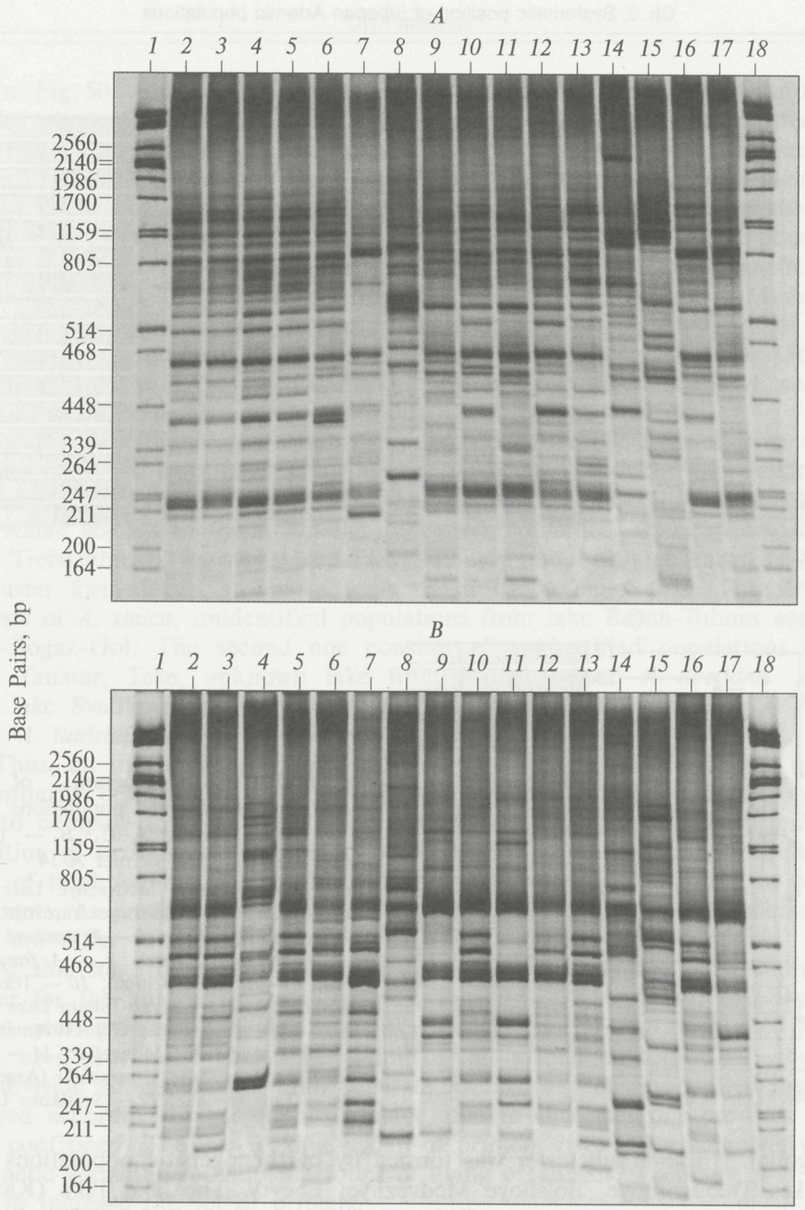


Fig. 49. RAPD-structures of 16 Artemia samples with using: *A* — primer A-01, *B* — primer A-09.

Lanes: *1*, *18* — ladder; *2* — Bolshoye Medvezhye Lake; *3* — Ebeyty Lake; *4* — Bolshoye Yarovoye Lake; *5* — Trebushinoye Lake; *6* — *A. urmiana* (Iran); *7* — *A. tibetiana* (China); *8* — *A. franciscana* (SFB); *9* — *A. sinica* (China); *10* — Teke Lake (Kazakhstan); *11* — Bayan-Tuhum Lake (Mongolia); *12* — Kara-Bogas-Gol (Turkmenistan); *13* — unknown lake (Mongolia); *14* — *A. tunisiana* (Egypt); *15* — *A. persimilis* (Argentina); *16* — Tanatar Lake; *17* — Svatikovo Lake.

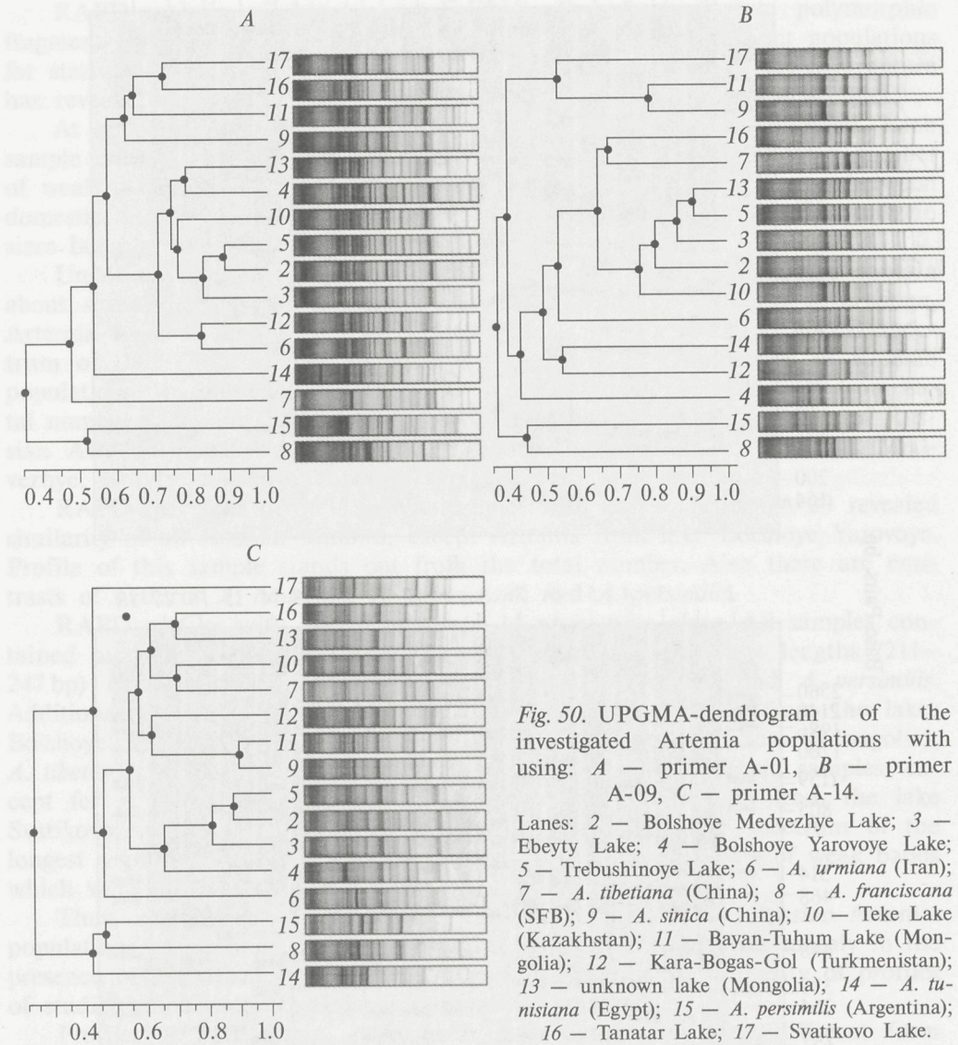


Fig. 50. UPGMA-dendrogram of the investigated Artemia populations with using: *A* — primer A-01, *B* — primer A-09, *C* — primer A-14.

Lanes: *2* — Bolshoye Medvezhye Lake; *3* — Ebeyty Lake; *4* — Bolshoye Yarovoye Lake; *5* — Trebushinoye Lake; *6* — *A. urmiana* (Iran); *7* — *A. tibetiana* (China); *8* — *A. franciscana* (SFB); *9* — *A. sinica* (China); *10* — Teke Lake (Kazakhstan); *11* — Bayan-Tuhum Lake (Mongolia); *12* — Kara-Bogas-Gol (Turkmenistan); *13* — unknown lake (Mongolia); *14* — *A. tunisiana* (Egypt); *15* — *A. persimilis* (Argentina); *16* — Tanatar Lake; *17* — Svatikovo Lake.

(Mongolia). Another subcluster was formed by parthenogenetic populations from the lakes Trebushinoye, Bolshoye Medvezhye, Ebeyty. The lake Teke (Kazakhstan) was in the same group too. This group was combined with lakes clustered together (index of similarity was equal to 0.80) with Artemia populations from the lake Bolshoye Yarovoye, unnamed lake from Mongolia, *A. urmiana* and population from the Gulf Kara-Bogaz-Gol (Turkmenistan) (index of similarity was 0.85). *A. tibetiana* and *A. tunisiana* were far from others. The third cluster consisted of *A. franciscana* and *A. persimilis*, i.e. species living in the waters of North and South America.

In Fig. 50*B* there is a dendrogram of similarity constructed with use of profiles obtained of primer A-09. The existence of two unequal clusters was also noted here. Large cluster consists two subclusters. One subcluster was formed by bisexual Artemia population from lake Svatikovo and *A. sinica*, as well as population from the lake Bayan-Tuhum. Forming the second subcluster begins with grouping of the most genetically similar Artemia populations from lake Trebushinoye and parthenogenetic population from Mongolia (genetic index of similarity is 0.90). Populations from the lakes Ebeyty, Bolshoye Medvezhye, Teke (Kazakhstan), as well as cluster Tanatar — *A. tibetiana* adjoin for them. *A. urmiana*, *A. tunisiana*, brine shrimps from the Gulf Kara-Bogaz-Gol and Bolshoye Yarovoye Lake are also in this group. *A. franciscana* and *A. persimilis* were allocated in outgroup.

In Fig. 50*C* there is a dendrogram of similarity constructed with use of profiles obtained with help of primer A-14. The analysis of the dendrogram showed the presence of two clusters. Large cluster consists of two subclusters; *A. urmiana* adjoins to them. Smaller subcluster combined *Artemia* from Russian lakes Trebushinoye, Bolshoye Medvezhye, Ebeyty and Bolshoye Yarovoye. Larger subcluster formed two groups at scale of similarity equel 0.55. The first one consists of *A. sinica*, unidentified populations from lake Bayan-Tuhum and Gulf Kara-Bogaz-Gol. The second one consists of unidentified populations of the lakes Tanatar, Teke, unknown lake from Mongolia and *A. tibetiana*. *Artemia* from lake Svatikovo spaced separately. The second cluster combines *A. franciscana*, *A. tunisiana* and *A. persimilis*.

Thus, all investigated Artemia samples were clustered based on the analysis of similarity of obtained profiles. Using of three primers allowed the opportunity to compare the results obtained in different experiments. The principle of operation of various primers consisted of isolation and amplification of different parts of total Artemia DNA with follow analysis. It was confirmed in our experiments, as profiles from the same lakes prepared with use of different primers are differ to each other.

At this stage of experiments it is difficult to identify the most appropriate primer for the analysis of total Artemia DNA. In our opinion, based on obtained phoregramms and dendrograms of similarity it can be noted primer A-01, used previously. Under the action of this primer on total DNA the clearest division of populations into separate groups was observed. Differentiation occured according to geographical factor, due to that fact our previous results were confirmed. The use of large group of primers gives more complete picture of genetic variability of studied groups of living organisms. Therefore it is necessary to increase the set of primers.

Analysis of three dendrograms revealed the existence of general trends. In all cases, outgroup consisted of analyzed Artemia populations from Europe (*A. tunisiana*), South America (*A. persimilis*) and North America (*A. franciscana*). Studied Siberian parthenogenetic *Artemia* populations (the lakes Ebeyty, Bolshoye Yarovoye, Bolshoye Medvezhye, Trebushinoye) formed common cluster. Bisexual population from lake Svatikovo was combined with *A. sinica*. Probably, they belong to the same group. These conclusios confirm our earlier results.

Dendrograms of similarity showed similar patterns of differentiated grouping of studied Artemia samples. Identification by RAPD — PCR due to direct comparison of profiles allowed to set relationship and distant of different Artemia populations. Based on phoregramms of RAPD-spectrum amplificates of total DNA of studied Artemia samples it is possible to state that all Russian populations belong to the same group, including bisexual population from the lake Tanatar.

3.3.4. Sequencing of cytochrome oxidase I (COI) mitochondrial DNA

The method of cluster constructing and cluster interpretation are often ambiguous. Identification by RAPD — PCR with help of direct comparison of profiles allows to set similarity and distant in different Artemia populations. In this regard, construction of phylogenetic system of *Artemia* genus based on mtDNA sequences by sequencing of nucleotides is more promising.

At present, the sequence analysis of mtDNA is considered the leading method in reconstruction of phylogenetic relationships in species and higher ranks. If RAPD and similar methods of analysis identify the population structure of species (up to individual genotyping of individual), due to scanning large number of anonymous loci of nuclear DNA, the comparison of DNA sequences allows to assess the degree of species divergence better. Thus, the method of genetic analysis, based on determination of nucleotide sequence (sequencing) was tested.

In this context, to assess the prospects of mtDNA analysis in order to determine the phylogenetic relationships in genus *Artemia*, initially gene sequences of cytochrome oxidase I (COI) from five populations of the lakes Kulundinskoye (As1) and Bolshoye Medvezhye (As5), *A. tibetiana* (As26), *A. persimilis* (As49), *A. sinica* (As30) were obtained (Fig. 51).

A multiple alignment of obtained sequences, as well as the site of the gene CO I from complete mitochondrial genome of *A. franciscana* (Genebank NC_001620) was conducted.

Preliminary results have demonstrated (Fig. 52), that populations of Artemia lakes Kulundinskoye (As1) and Bolshoye Medvezhye (As5) are almost identical. *A. tibetiana* was the closest to these populations (As26) (2 replaces in 100 nucleotides or 2.2 % of divergence). There is a divergence (17–19 %) between Siberian populations, *A. sinica* (As30) and *A. franciscana*. Divergence encloses 21 % between Siberian populations and the most remote *A. persimilis* (As49).

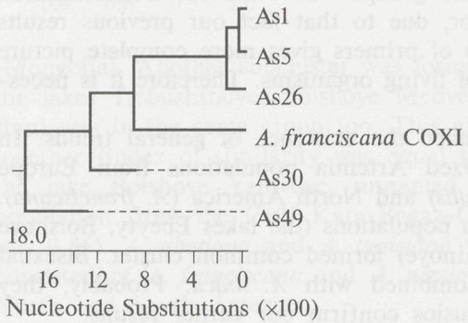
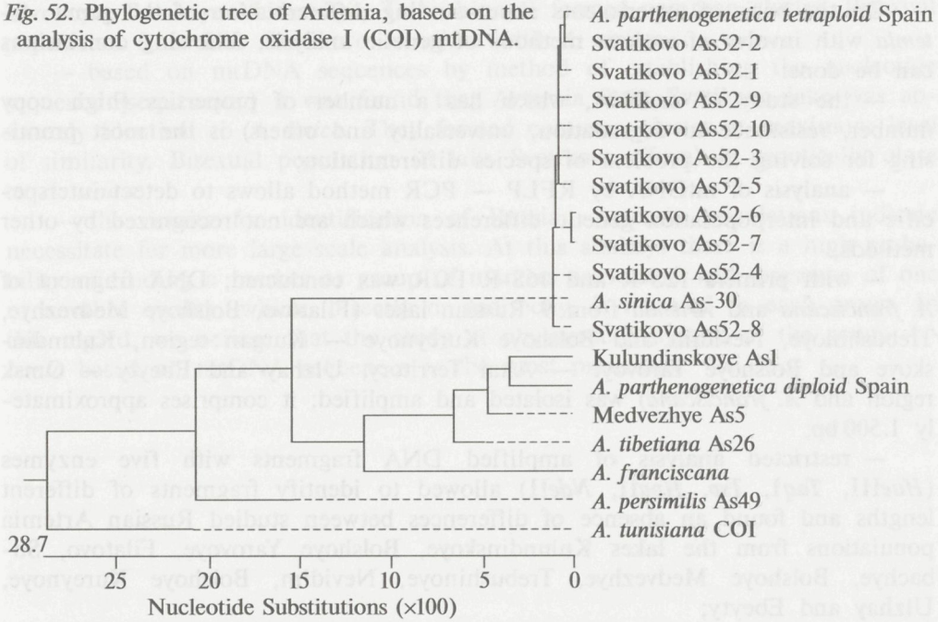


Fig. 51. Preliminary analysis of cytochrome oxidase I (COI) mtDNA.

Fig. 52. Phylogenetic tree of Artemia, based on the analysis of cytochrome oxidase I (COI) mtDNA.



Due to molecular genetic analysis of bisexual populations from lake Svatikovo the range of tasks was extended. In particular, it was interesting to examine phylogenetic relationships between known Artemia species and Russian populations with bisexual type of reproduction.

Artemia from lake Svatikovo was absolutely identical to *A. sinica*, they formed single cluster at maximal level of similarity. The second cluster was formed by Artemia populations from studied the lakes Kulundinskoye, Bolshoye Medvezhye and *A. tibetiana*. *A. franciscana*, *A. persimilis* and *A. tunisiana* were the most genetically distant.

It can be concluded that *A. tibetiana*, *A. sinica*, *A. persimilis* and *A. franciscana* are quite distinct species. According to our data, bisexual Artemia from lake Svatikovo can be defined as *A. sinica*. Phylogenetic relationships between different Artemia populations require further analysis.

It is noted genetic closeness of parthenogenetic Artemia populations from Russia, Kazakhstan, Turkmenistan, Mongolia and bisexual populations identified as *A. urmiana* and *A. tibetiana*.

Thus, on the basis of phoregramm RAPD-spectrum amplificates of total DNA, as well as COI mtDNA analysis of studied Artemia samples it can be stated that all parthenogenetic Siberian populations belong to the same group.

The resulting regularity are agree with geographic location of analyzed lakes, as well as Artemia biological characteristics, in particular with type of reproduction (bisexual or parthenogenetic).

On the basis of experiments about studing differentiation of the genus *Artemia* with involve of various methods of genetic analysis, following conclusions can be done:

— the study of mtDNA, which has a number of properties (high copy number, resistance to degradation, universality and others) is the most promising for solving the problem of species differentiation;

— analysis of mtDNA by RFLP — PCR method allows to detect interspecific and interpopulation genetic differences which are not recognized by other methods;

— with primers 12S-R and 16S-R PCR was conducted; DNA fragment of *A. franciscana* and *Artemia* from 9 Russian lakes (Filatovo, Bolshoye Medvezhye, Trebushinoye, Nevidim and Bolshoye Kureynoye — Kurgan region, Kulundinskoye and Bolshoye Yarovoye — Altai Territory, Ulzhay and Ebeyty — Omsk region and *A. franciscana*) was isolated and amplified; it comprises approximately 1.500 bp;

— restricted analysis of amplified DNA fragments with five enzymes (*Hae*III, *Taq*I, *Tsp*, *Hpa*II, *Nde*II) allowed to identify fragments of different lengths and found an absence of differences between studied Russian Artemia populations from the lakes Kulundinskoye, Bolshoye Yarovoye, Filatovo, Sobachye, Bolshoye Medvezhye, Trebushinoye, Nevidim, Bolshoye Kureynoye, Ulzhay and Ebeyty;

— RFLP — PCR revealed the presence of differentiation between studied Artemia samples from Russian populations and *A. franciscana* inhabiting in the USA;

— analysis of total DNA by RAPD — PCR allowed to allocate polymorphic fragments in representatives of 31 Artemia samples from different habitats for statistical evaluation;

— identification by RAPD — PCR with help of direct comparison of profiles allowed to establish extent of similarity and differences in studied Artemia populations. All studied samples of Siberian Artemia populations (including bisexual population from lake Tanatar) belong to the same group;

— on the basis of analysis of frequency obtained profiles in different Artemia populations it should be noted genetic affinity of investigated Artemia samples from reservoirs of Russia, Kazakhstan, Turkmenistan and Mongolia, *A. urmiana*, *A. sinica* and *A. tibetiana*;

— despite the lack of clear correlation between the nature of distribution of DNA fingerprints in dendrogram and geographical location of reservoirs, as well as belonging to certain species, there is a tendency to group individuals united by geographical factor;

— analysis of dendrogram of similarity constructed on data of frequency of selected fragments obtained with three different primers A-01, A-09 and A-14 revealed identical patterns of differential clustering of test Artemia samples. Analyzed Artemia populations from Europe (*A. tunisiana*), South America (*A. persimilis*) and North America (*A. franciscana*) were in outgroup. All Russian parthenogenetic Artemia populations (from the lakes Ebeyty, Bolshoye Yarovoye, Bolshoye Medvezhye, Trebushinoye) formed common cluster. Bisexual population from lake Svatikovo is adjoin with *A. sinica*;

— based on mtDNA sequences by method of establishing the nucleotide sequence (sequencing) it was found that Artemia from Svatikovo lake was absolutely identical to *A. sinica*. They formed common cluster at maximum level of similarity. Bisexual population in lake Svatikovo (Tuva) is genetically close to *A. sinica*;

— the results for identification of Russian Artemia populations indicate necessitate for more large-scale analysis. At this analisys there is a high probability of finding a marker or group of markers associated with presence of one or another quality, which, directly or indirectly, is revealed in each group. In this regard, we believe that the study of phylogenetic system of the genus *Artemia* based on mtDNA sequences is the most promising.

Chapter 4

PECULIARITIES OF BIOLOGY AND ECOLOGY OF ARTEMIA IN THE SIBERIAN BIOTOPES

4.1. Reproduction, fecundity and sex ratio

In Siberian lakes, there is a notable female predominance in sex the composition of parthenogenetic brine shrimp (*Artemia*) population (99.3 % on average of most lakes), though sex ratio may noticeably change for the same population within and between years. The Artemia population is represented by parthenogenetic strains in all lakes investigated in Kurgan, Omsk, Chelyabinsk regions, though in approximate half of the lakes the Artemia population consisted exclusively of females. Males were observed in the other lakes (0.2–2.2 % of total number of adults). There were exceptions in some of the lakes, such as the population in lakes Sobachiye (20 % male in 2000), Bolshoye Kureinoye (3.6 % male in 2001), Oktyabrskoye (6.7 % male in 2001). In the Altay area, parthenogenetic Artemia strain was predominant but proportion of males was higher in populations of some lakes reaching in particular periods 7.7 % in Lomovoye (2001), 29.0 % in Yodnoye (2001), 9 % in Bolshoye Yarovoye (2003), 33 % in Malinovoye (2002) and even 75 % in Tanatar I lake (2002). As a rule, in typical bisexual populations, the proportion of males always exceeds 30 % (42.4 % on average). Thus, in Tus lake (Khakasia) males in plankton made up 43 % of the population in 2000, 32 % in 2004 and in Svatikovo lake (Tuva) it was 58 % in 2000 and 36 % in 2004. According to our data as well as to the literature data (Studenikina, 1986a,b), the Artemia population in Tanatar lake can be related to bisexual. The same category can be reffered to Solenoye lake in the Altay area (Studenikina, 1986a,b; Solovov, Studenikina, 1990) where a bisexual population inhabited this lake during few years of scientific observation. In 1981, an increase in male numbers from June up to August from 10 to 67 % was observed in this lake. The data on the Artemia sex-ratios of Kulundinskoye Lake remains uncertain. V.P. Solovov and T.L. Studenikina (1990) mention that the adult sex ratio in this lake is in equal proportion. However, our research conducted in 2002 showed an absolute domination of females (i.e. the proportion of males was not higher than 1 %). In the following publications of our research team and the aforementioned authors concur that parthenogenetic strain was generally prevails (Litvinenko et al., 2004).

In the lakes of this region the highest individual brood size made up 145–150 embryos. The mean value of this parameter in different years in water bodies of South Siberia was in the range between 15 to 35 embryos. According

to all our studies of parthenogenetic population it made up 22.6 on average and for the bisexual strain a mean of 24.6 embryos per gravid female (App. 24).

According to the scientific field observations, the duration of the maturation period of the Siberian population in natural conditions is 3–5 weeks. For the initial spring generation it is 4–5 weeks while for the summer generation it is 3–4 weeks, and it is 2–3 weeks for those cultured in the laboratory under optimal conditions.

Among the summer generation of females there was both ovoviviparous and oviparous reproduction. Among the oviparious females, the cysts that were classified as "thinshell" or "summer cysts". Other females reproduced viviparously and had eggs and nauplii in their ovisacs. There were no females with nauplii in ovisacs in autumn generation, but females with "thinshell" cysts in ovisacs were rarely observed. At the same time the female fertility rate was higher than the typical average summer indicator of 40 % gravid females in most populations.

In general, the proportion of cyst clutches per season averaged 67.2 % over all populations with an average of 23 cysts per clutch. The proportion of clutches with eggs was 32 % with an average of 20 eggs per clutch, and the proportion of clutches with nauplii was 0.8 % with an average of 19 nauplii per clutch. In terms of the entire population the average brood size in one clutch was 15.5 cysts, 6.4 eggs and 0.2 nauplii, which was respectively 70, 29 and 1 %.

Artemia fecundity (fertility) is quite variable can change considerably within and between seasons or years (see App. 24). Inter-annual variability of this sign (C_v) in different lakes is equal to 1.9–95.8 and makes up 55 % on average for all parthenogenetic populations and 31 % for bisexual populations. Conversely, the variability of population sex ratio is low in parthenogenetic populations: C_v from 0 to 10.2 %, 0.95 % with an average. There is slightly variability for the bisexual populations: Cv from 12.7 to 29.6 % with an average of 21 %.

The total number of clutches during the life cycle was calculated according to the formula (Khmeleva, Giginyak, 1982):

$$N = 1.35\left(\frac{l_{\max}}{l_{\min}}\right)^{2.5},$$

where N — total number of clutches; $l_{\max}$ — maximal length of matured females in population, mm; $l_{\min}$ — minimal length of matured females in population, mm.

According to the calculations in different populations the number of clutches during life cycle was in the range from 2 to 10 and on average was equal to 4.54 ± 0.37 mg.

The absolute value of individual weight of matured female, with full ovisac ranged from 1.0 to 12.8 mg in the lakes studied, the average population value (App. 25) ranged from 1.6 to 11.9 mg with an average value for all populations of 4.18 ± 0.14; $n = 121$; $C_v = 38$ %. The absolute value of this parameter in particular population differed in 1.2–5.3 times during season with an average of 2.0 times. The average seasonal value of this parameter in various years in the same lake changed in 1.2–3.1 times with an average of 1.8 times.

The rate of body weight increment ($C_w = \ln(w_2/w_1)/(t_2 - t_1)$, where w_1 and w_2 are weights of the organism in the beginning (t_1) and in the end (t_2) of the period under consideration, which was calculated for the period of hatching up to mature stage of brine shrimp of the first generation. This rate for various populations in natural conditions ranges from 0.14 to 0.20, and in laboratory cultivation from 0.19 to 0.37 day^{-1}. The laboratory cultivation was conducted in conditions close to optimal (23–26 °C and 35 ‰ salinity). Probably, the closer the natural conditions are to optimum, the faster is the rate of maturation at a lower height and weight of shrimps. Higher somatic growth rate for the first 9 days of cultivation under similar conditions of various strains of the New and Old World are given in the literature where it was reported to be: C_w within 0.343 to 0.485 day^{-1} (Lavens, Sorgeloos, 1991). According to that rate, the population of Tientsin lake in China is more similar to Siberian lakes where the C_w is equal to 0.343 when the temperature is 23 °C and 0.371 day^{-1} when the temperature is 25 °C. Moreover, it should be noted that the data for the whole period of cultivation (from 20 till 35 days) is cited, and it is known that both younger stage Artemia (Zaika, 1983) and crustaceous (Ivanova, 1985) have higher value of C_w (at S-shape growth).

The individual weight of mature males in the lakes surveyed was approximately 1.4 times lower than the weight of females (see App. 25) and its average population values ranged from 1.0 to 6.6 mg with an average of 3.03 ± 0.16; $n = 54$; $C_v = 34$ %.

The weight of freshly hatched nauplii from different populations ranged from 0.013–0.018 mg with an average of 0.015 mg.

The absolute sizes of Artemia cysts in the lakes was within the range from 204 to 372 µm and the average for multiple population was from 230 to 290 µm in diameter. Generally, for all populations this parameter was equal to 260 ± 10 µm, $C_v = 4.3$ % (App. 26). The diameter of "thinshell" cysts (i.e. summer cysts) was within the range from 0.19 to 0.22 mm. The weight of dry cysts was 0.0044–0.0068 mg on average. The weight of crude cysts, depending on their sizes ranged from 0.007 to 0.013 mg and was equal to 0.01 mg on average for all populations.

Thus, the natural population of Siberian *Artemia* is characterized by domination of parthenogenetic strain, ovoviparous reproductive mode (i.e., cyst production), relatively low individual fertility and low rate of body weight increment. Thus, the dimensions are within the scope of Artemia shrimps known in the literature for different populations (see Sect. 1.5).

4.2. Peculiarities of Artemia population density dynamics in the lakes of Western Siberia

4.2.1. Density seasonal dynamics of various Artemia age classes

Artemia nauplii hatching from cysts in the lakes of Western Siberia is observed from the second half of April onward when water temperature warms to 4–5 °C. One to three peaks of nauplii and metanauplii density was observed in the seasonal dynamics. As a rule, the first peak is registered in April to

May. It is the highest value observed and reaches significant values in some populations: 5164 ind./l (Maloye Medvezhye on April 19, 2001) and 2196 ind./l (Filatovo on April 24, 2001). In most cases this peak value is within the range of 10 to 1000 ind./l and makes up 330 nauplii/l on average. The summer peak (June and July), determined by ovoviparity (i.e., eggs that hatch in ovisac) are not always registered and is much low than the first peak. The last date when nauplii was observed in plankton was October 5 in quantity of 0.34 ind./l (Nevidim, 2002).

The maximal density of juveniles in the seasonal dynamics was observed at the end of May with 25 ind./l on average. In some lakes, the density of juvenile Artemia reaches the values of 182–197 ind./l (Bolshoye and Maloye Medvezhye, 2001). A second and third maximum were rarely observed and did not exceed 20 ind./l. The last date when juvenile Artemia in plankton met was September 22 in quantity 0.28 ind./l (Maloye Medveshye, 2000).

The adults and pre-adults started to show up at the end of May and June. Sporadically, pre-adults were already registered in May 8. A broad peak of pre-adults density covers 2 months (June and July). The density of this age class did not exceed 64 ind./l and the average for the period (for all lakes) was approximately 6 ind./l. The dynamics of adults showed 1–3 peaks, and the maximal value of 62.6 ind./l was observed in 2002 in Cherdynskoye lake. These shrimps were found in plankton of lakes until mid-October at water temperature of 3–12 °C. Sporadic live Artemia was registered at water temperature of minus 3 °C in Ebeyty lake in November of 2003.

In annual dynamics of planktonic and benthic cysts (App. 27, 28) there were winter minima, two maxima for the benthic cysts and 2–3 maxima for the planktonic cysts. The absolute values of planktonic cysts numbers are in the range from 0.1 to 3720 ind./l, and for benthic cysts from 0 to 18 600 thousand ind./m^2. During the period of minimum the number of planktonic cysts, as a rule, is not higher than 3 ind./l and not higher than 400 thousand ind. /m^2 for benthic cysts. In rare cases, the number of planktonic cysts goes up to 102–482 ind./l and to 870–2200 thousand ind./m^2 for benthic cysts. The first maximum of cyst density is observed in April and May and caused by the washing out of shoreline accumulation by melting snow. In some lakes, that period the density of planktonic cysts reached its highest value: 2015 ind./l (Maloye Medvezhye, 2001) and even 3720 ind./l (Vishnyakovskoye, 2002). The density of benthic cysts increases up to 580–6000 thousand ind./m^2 in various lakes. The hatching percentage, in this period, is equal to 35 % on average for planktonic and 16 % for benthic cysts.

The second maximum in plankton, determined by laying eggs and cysts by brine shrimp of the second generation, occurs, as a rule, in July and August, and the third maximum is determined by laying cysts by the second and third generations brine shrimp and is often observed in November. The second density peak is as great as the third peak and even prevalent in some populations. The density of planktonic cysts during the first peak can reach from 150 to 2630 ind./l, and the second peak can reach from 110 to 1420 ind./l. The hatching rate of planktonic and benthic cysts released in summer was in the range from 2 to 18 % with an average of 9 %, $n = 14$.

Table 19. **Ratio of actual benthic and planktonic cysts number to seasonal average or annual average values (all data of model lakes)**

Months of the year	Benthic cysts						Planktonic cysts					
	For the season			For the year			For the season			For the year		
	M	σ	C_v, %	*M*	σ	C_v, %	*M*	σ	C_v, %	*M*	σ	C_v, %
I				0.26	0.29	113				0.02	0.01	74
II				0.57	0.59	104				0.05	0.12	258
III				0.55	0.61	112				0.27	0.52	191
IV				1.06	1.29	122				1.44	3.17	220
V				0.77	0.97	126				1.23	1.54	125
VI	0.85	0.77	91	1.14	1.18	103	1.04	0.96	92	1.67	1.84	110
VII	0.91	0.54	59	1.06	0.73	69	1.1	1.13	103	0.66	0.49	74
VIII	0.79	0.51	65	0.97	0.73	76	1.64	1.53	94	2.62	2.62	100
IX	1.48	1.05	71	2.13	1.79	84	0.87	0.61	70	1.43	1.17	82
X	1.09	0.8	73	1.28	0.95	74	0.58	0.52	90	0.79	0.97	123
XI	0.86	1.04	122	1.00	1.10	111	0.78	0.96	123	1.17	1.87	160
XII				0.69	0.79	115				0.41	0.47	115

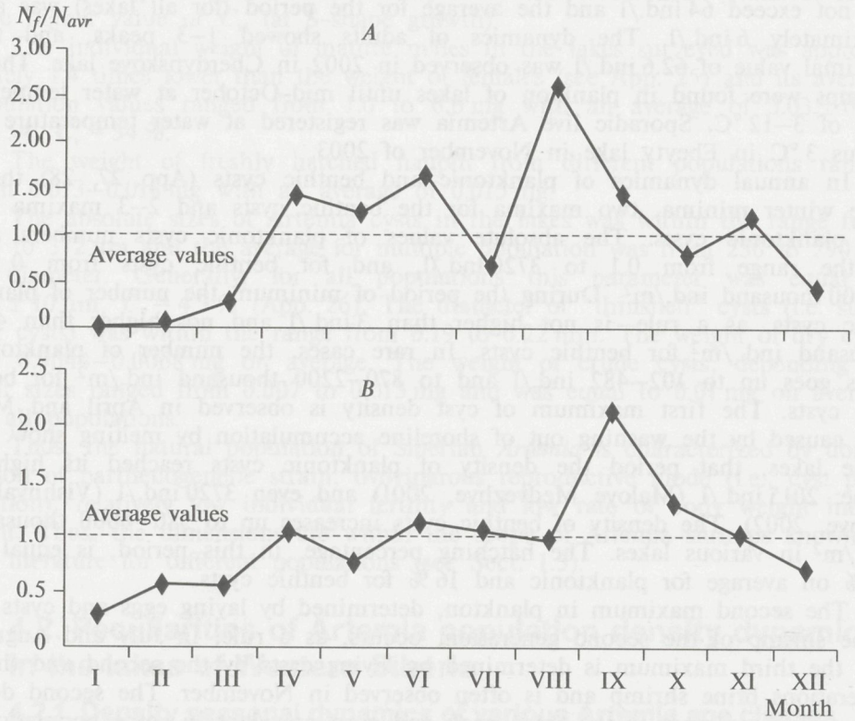


Fig. 53. Annual dynamics of deviations of planktonic (*A*) and benthic (*B*) actual number cysts (N_f) from average values on one year (N_{avr}) (according to monitoring for 2000–2004).

The second peak in benthos occurs mainly in September. The autumn peak is the highest reaching up to 1900–18 600 thousand ind./m². The hatching rate of cysts laid in autumn was in the range from 1.8 to 31.3 % with an average of 19.9 %, $n = 42$.

The analysis of all monitoring data of actual number of planktonic and benthic cysts from average per month deviation allowed detecting a particular seasonal and annual dynamics of cyst number (Tab. 19). According to the annual dynamics (Fig. 53*A*) the maximum planktonic cysts density occurs in August, the minimum density occurs in winter and some increase starting from April to June. The variability of deviations of actual cysts density from annual average is the lowest in summer. The peak benthic cysts density occurs in September (see Fig. 53*B*) and the minimum density occurs in winter and some increase in April and June. The variability of deviations of actual cysts density from annual average is the lowest from April to August.

4.2.2. Seasonal dynamics of brine shrimp Artemia total biomass and density

In the seasonal dynamics of the total number of brine shrimp (Fig. 54) there was observed a single peak in April — May in 57 % of the population (one case was observed in June) and two peaks mainly occurred in April and

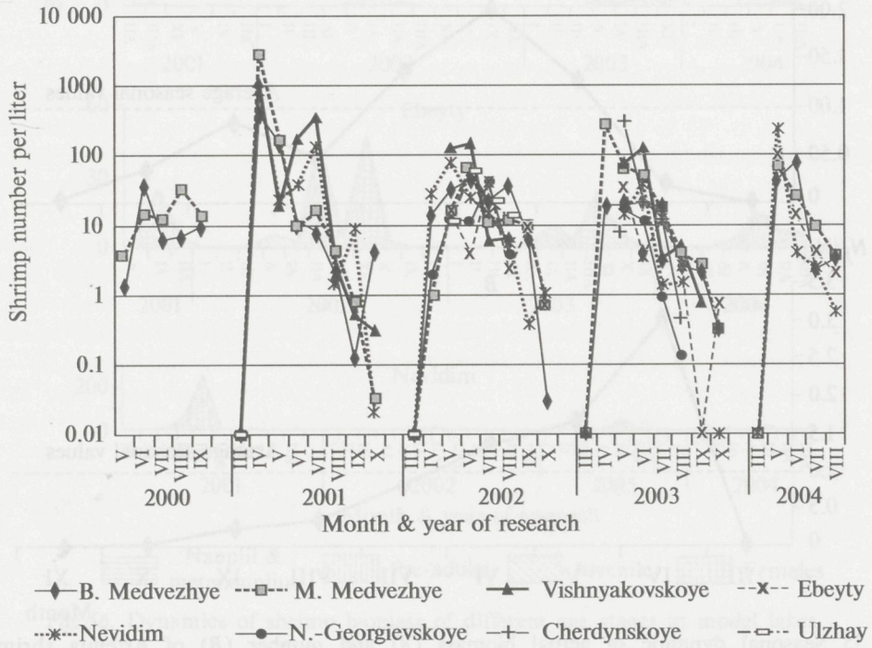


Fig. 54. Seasonal dynamic of total number of Artemia shrimps in model lakes.

June — July in 43 % of the population. The peak density in April and May occur due to nauplii and juvenile brine shrimp, and in the following months due to pre-adults and adults presence.

When the population of brine shrimp is at its peak, their number reached a significant value in some model lakes: an average of 2739 ind./l in Maloye Medvezhye in April and May in 2001, in Vishnyakovskoye lake was 1143 ind./l and it was 893 ind./l in Nevidim lake.

The percentage of different Artemia age classes in two lakes Bolshoye Medveshye and Nevidim in three seasons of scientific research (2001–2003) is shown in App. 29. Cysts and nauplii were predominant in the plankton in the beginning of season, juveniles predominated in May, and from June to October adults and pre-adults dominated. Cyst density in plankton starts to build up numbers in August.

After all data available from the monitoring studies is summed up, the seasonal dynamics of total number of Artemia brine shrimp relative to average values is obtained (Fig. 55). The Figure shows that the brine shrimp Artemia density in April — June is higher than the average seasonal values, and it is lower in other months. The maximum Artemia density is observed in April. There was a gradual decrease in density from April through the end of the

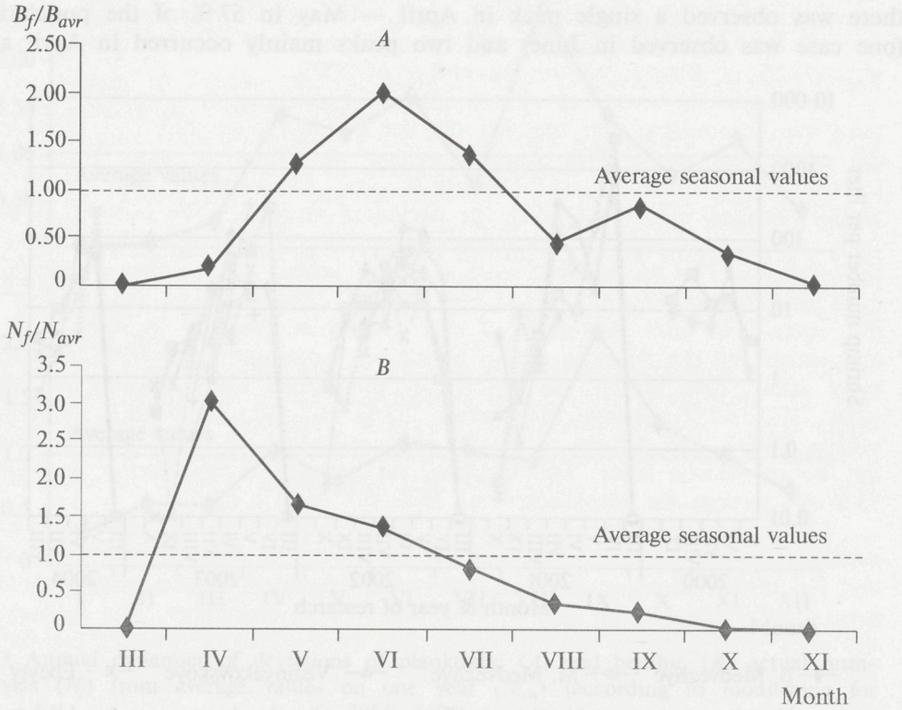


Fig. 55. Seasonal dynamic of actual biomass (*A*) and number (*B*) of Artemia shrimps concerning average values (according to monitoring 2000–2004).

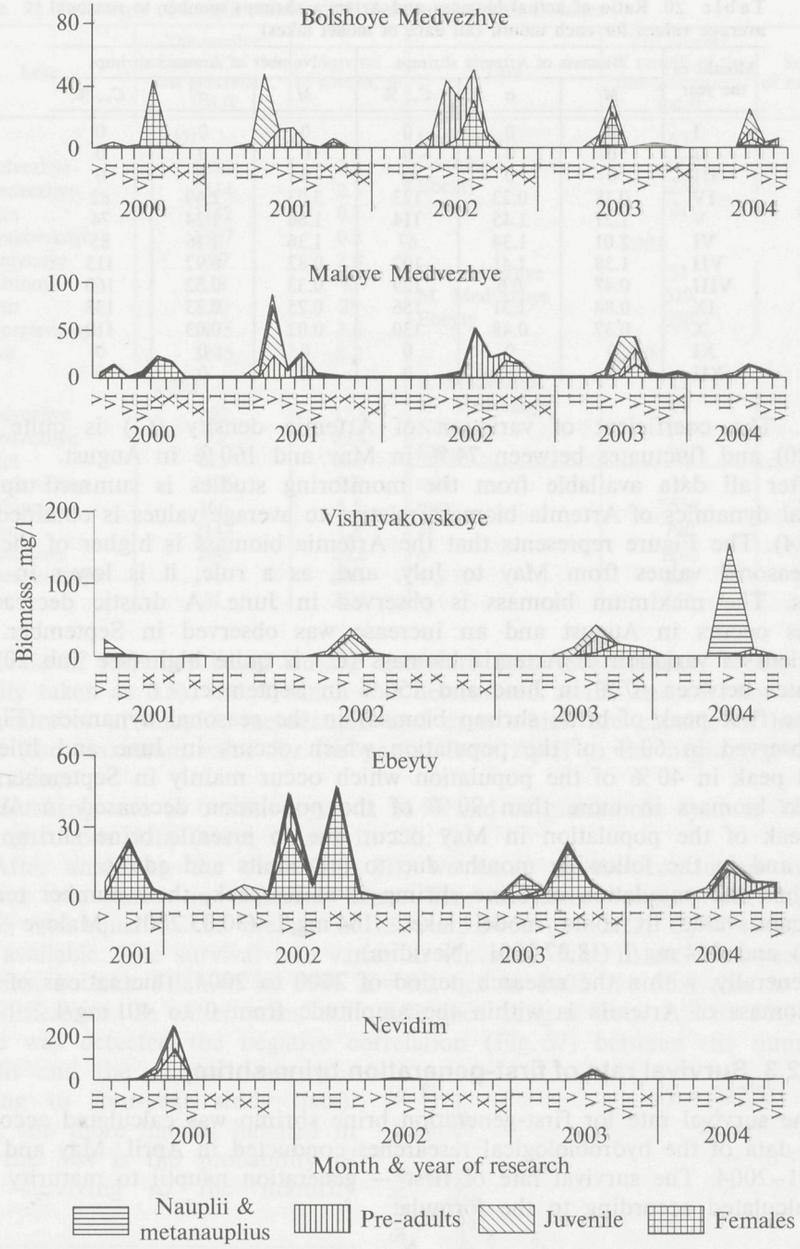


Fig. 56. Dynamics of shrimp biomass of different age stages in model lakes.

Table 20. **Ratio of actual biomass and Artemia shrimps number to seasonal average values for each month (all data of model lakes)**

Months of the year	Biomass of Artemia shrimps			Number of Artemia shrimps		
	M	σ	C_v, %	*M*	σ	C_v, %
I	0	0	0	0	0	0
II	0	0	0	0	0	0
III	0	0	0	0	0	0
IV	0.18	0.23	123	3.03	2.49	82
V	1.27	1.45	114	1.66	1.24	74
VI	2.01	1.34	67	1.36	1.16	85
VII	1.38	1.41	102	0.82	0.92	113
VIII	0.47	0.6	129	0.33	0.52	160
IX	0.84	1.31	156	0.25	0.33	133
X	0.37	0.48	130	0.02	0.03	110
XI	0	0	0	0	0	0
XII	0	0	0	0	0	0

season. The coefficient of variation of Artemia density (C_v) is quite high (Tab. 20) and fluctuates between 74 % in May and 160 % in August.

After all data available from the monitoring studies is summed up, the seasonal dynamics of Artemia biomass relative to average values is obtained (see Fig. 55*A*). The Figure represents that the Artemia biomass is higher of the average seasonal values from May to July, and, as a rule, it is lower in other months. The maximum biomass is observed in June. A drastic decrease of biomass occurs in August and an increase was observed in September. The coefficient of variation of Artemia biomass (C_v) is quite high (see Tab. 20) and fluctuates between 67 % in June and 156 % in September.

The first peak of brine shrimp biomass in the seasonal dynamics (Fig. 56) was observed in 60 % of the population which occurs in June and Jule and second peak in 40 % of the population which occur mainly in September. The Artemia biomass in more than 90 % of the population decreased in August. The peak of the population in May occur due to juvenile brine shrimp presence, and in the following months due to pre-adults and adults.

When the population of brine shrimp is at its peak, their number reached significant value in some model lakes: 164 mg/l (30.05.2001, Maloye Medvezhye) and 254 mg/l (18.07.2001, Nevidim).

Generally, within the research period of 2000 to 2004, fluctuations of summer biomass of Artemia is within the amplitude from 0 to 401 mg/l.

4.2.3. Survival rate of first-generation brine shrimp

The survival rate for first-generation brine shrimp was calculated according to the data of the hydrobiological researches conducted in April, May and June of 2001–2004. The survival rate of first — generation nauplii to maturity stage was calculated according to the formula:

$$K = \frac{N}{n} \cdot 100,$$

where N — maximal number of sexually matured, pre-adult and juveniles (sur-

Table 21. **Indicators of nauplii number and their survival rate in lakes**

Lake	The number of nauplii of the first generation, ind./l	Survival of nauplii, %	Lake	The number of nauplii of the first generation, ind./l	Survival of nauplii, %
2001			Umreshevo	63	2.4
B. Medvezhye	1200	7.9	Gashkovo	107	0.3
M. Medvezhye	5554	2.3	Ebeyty	1230	1.3
Nevidim	1142	0.7	Ulzhay	21	62.8
Vishnyakovskoye	1307	0.8	*2003*		
B. Kureynoye	509	2.0	B. Medvezhye	31	67.6
Trebushinoye	118	42	M. Medvezhye	519	9.5
Aktoban	120	29	Ebeyty	570	0.5
N.-Georgievskoye	1875	3.6	*2004*		
Filatovo	3245	0.2	B. Medvezhye	43	8.8
2002			M. Medvezhye	69	2.5
B. Medvezhye	202	17.8	Nevidim	243	1.4
M. Medvezhye	92	69.4	Ebeyty	95	6.9
Nevidim	613	0.6	min	21	0.2
Vishnyakovskoye	1306	2.8	max	5554	69.4
Trebushinoye	166	6.5	*M*	790	15.1
Aktoban	2142	1.8	σ	1203	21.2
Cherdynskoye	246	29.8	C_v, %	223	140.7
N.-Georgievskoye	46	20.1	*m*	152	3.9
Filatovo	31	36.6			

vival rate of juveniles based on the literature data (Studenikina, 1991), conditionally taken as 0.5), ind./l which was determined at the end of May — June; n — number of nauplii, metanauplii and cysts which are capable of hatching, ind./l (the maximum value for the period from April to the beginning of May was taken).

Hatching rate of benthic cysts is 16 % and of planktonic cysts is 35 % according to our data (more details in Ch. 7).

After analyzing the data (Tab. 21), we came to the conclusion that the survival rate varies in different lakes. This indicator ranges from 0.2 % to 69.4 % and equal to the average of 15.10 ± 3.94 % (σ = 21.2, C_v = 141 %) to all data available. The survival rate varies in the same lake in different years. For instance, in lake Filatovo in 2001 K = 0.2 but in 2002 K = 36.6 that is 183 times difference. In other lakes that difference ranged from 2.3 to 30.2 times. There was detected the negative correlation (Fig. 57) between the number of nauplii and the survival rate (according to four-year study data). Thus, the more nauplii hatched in lake the less is the probability of their surviving to the maturity stage.

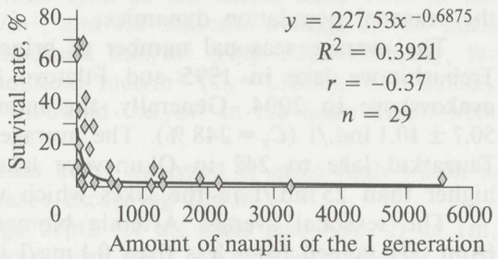


Fig. 57. Dependence between amount of nauplii of the I generation and their survival rate.

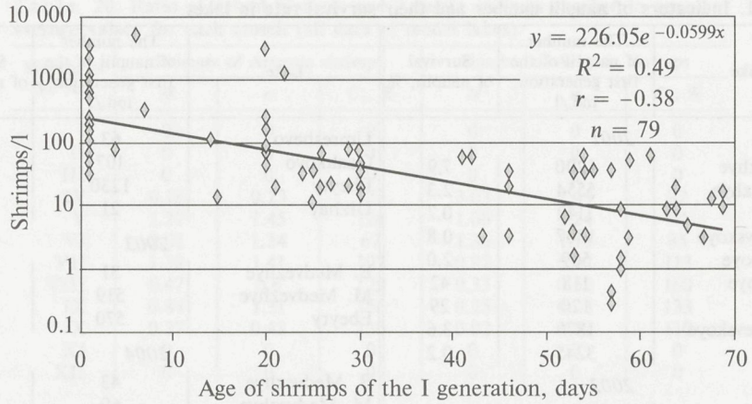


Fig. 58. Dynamics of survival rate of Artemia shrimps of I generation in lakes of Kurgan and Omsk regions according to data 2001–2004.

The dynamics of first-generation numbers of brine shrimp in Artemia lakes in Kurgan and Omsk regions according to the data of the years 2001–2004 is presented in Fig. 58. The figure shows that in spite of significant number of first generation nauplii, around 20 individuals in the average can survive to maturity stage.

4.2.4. Average annual and seasonal population density

All data available for Artemia density from 10 years of scientific research was analyzed. Since samples were collected not on fixed date strictly but they were collected at different times during the season and it was necessary to conditionally average them. Based on the monitoring researches conducted from the year of 2000 to 2004, the deviation values of actual Artemia biomass, number of planktonic and benthic cysts from mean values per season and a year by each month of the year were determined (see Tab. 19, 20). The use of coefficient of deviation allowed us to use all available population density values for analyses. Rare studies for the season were converted to the category of average seasonal. A further comparison was made at the level of average values. The advantage of the analysis of the average data prior to analysis for a certain is associated with the elimination temperature factor effect which determines the seasonal population dynamics.

The average seasonal number of brine shrimp (App. 30) ranged from 0 in Trebushinoye lake in 1995 and Filatovo lake in 2003 to 1139 ind./l in Vishnyakovskoye in 2004. Generally, the number of brine shrimp for all lakes is 50.7 ± 10.1 ind./l (C_v = 248 %). The average data on each lake ranged from 2 in Tauzatkul lake to 242 in Okunevoye lake. The number of brine shrimp was higher than 25 ind./l in the lakes which were more perspective for harvesting.

The seasonal average Artemia biomass in lakes for 10 years of research (App. 31) ranged from less than 0.1 mg/l in Tauzatkul in 2001, in Filatovo and

Trebushinoye lakes in 2003 to 181 mg/l in Soleniy Kulat in 2001 and even 220 mg/l in Okunevskoye lake in 1997. During the whole period of scientific research, Artemia was not found in relatively large lake of Siverga with the area of 52.13 km^2, but there was observed crustaceans *Branchinectella media* in small amounts. According to the earlier research performed by the specialist of SibrybNIIproekt (now Gosrybcenter) in the years of 1978, 1979 and 1989, the Artemia population density in this lake dropped drastically in high water year at salinity 25 g/l and was on an average level (Artemia biomass in August was 15 mg/l, in October — 4 mg/l) in low water year at salinity of 66–99 g/l.

Of all the data available for the seasonal average of Artemia biomass (see App. 31), the low level (lower than 10 mg/l) was observed in 51 % of cases, the average level with 10 to 30 mg/l in 23 % of cases and the high level with 31–50 mg/l in 10 % of cases and the highest biomass level with more than 50 mg/l in 16 % of cases. Generally, according to the data obtained during 10 years of scientific research, the seasonal average value was 23.8 ± 2.8 mg/l (C_v = 142 %).

The analysis of the average value of Artemia biomass in 29 lakes for the 10 years showed that 10 lakes (35 %) were low productive with Artemia biomass lower than 10 mg/l, 11 lakes (38 %) were medium productive with 10–30 mg/l of biomass, 7 lakes (24 %) were highly productive with 31–50 mg/l of biomass and 1 lake (3 %) was very highly productive with more than 50 mg/l of biomass. The average Artemia biomass value in 29 lakes was 23.3 ± 5.3 (C_v = 122 %).

Thus, two ways of the calculation of average Artemia biomass by all seasons in all lakes investigated and according to the long-term average values of some lakes showed the similar result. This value of 23 mg/l, in spite of high coefficient of variation, can be used in rough prediction of productivity of Artemia lakes in southwest Siberia.

In the model lakes the average annual indicators of planktonic cysts density was in the range of 106–281 ind./l, and average seasonal was 10–517 ind./l. The average seasonal values were from 0 to 801 ind./l (App. 32) for all lakes investigated (with conversion to coefficient of N_f/N_{avr}). Generally, for all lakes this value was 129.0 ± 13.2 ind./l (C_v = 126 %). The density of planktonic cysts was higher than 100 ind./l in the lakes which are more perspective for harvesting.

The average annual values of benthic cysts in the model lakes were in the range from 76 to 3774 thousand ind./m^2, and the seasonal average for all lakes investigated it was from 3 to 7165 thousand ind./m^2 (App. 33). Generally, for all lakes that value was 710 ± 116 thousand ind./m^2 (C_v = 156 %). The density of benthic cysts was higher than 500 thousand ind./m^2 in the lakes which were more perspective for harvesting.

The level of variability of the values being analyzed is quite high which is proven by the value of C_v in most cases exceeding 100 %.

If conditionally to take the average depth for all lakes (see App. 2) as 1m, then there is approximately 850 thousand cysts per 1 m^2 of a lake whereas 13 %

of them are in water column and 87 % are on the bottom. Based on the weight of crude cysts there are around 85 kg of cyst per 1 ha on average according to Siberian Artemia population investigated. This number can be used to roughly predict the productivity of Artemia lakes in western Siberia. For a particular lake with known depth an approximate productivity from 1 ha of water surface will be equal to $85 \cdot H$ (kg), where H — lake depth (m).

Thus, the productivity of cysts in Siberian lakes is quite high. These values correspond to cyst yield in productive biotope (Persoone, Sorgeloos, 1980; Camara, Rocha, 1987; Quynh, Lam, 1987), but considerably less than productivity of ponds in Thailand which is 153 kg/(ha · season) (Tarnchalanukit, Wongrat, 1987) and in Philippines which is 70 kg/(ha · month) in dry weight (Jumalon et al., 1987). However, a considerable portion of Artemia cysts in shallow lakes of western Siberian is unavailable for harvesting as they settle on the bottom.

4.2.5. The seasonal dynamics of Artemia population density in different years with different climatic conditions

Over the five-year period of monitoring studies from 2000 to 2004, the year of 2000 proved to be the most anomalistic because of increase of water temperature up to 35–38 °C and decrease in the amount of dissolved oxygen in water up to 0 mg/l and there occured mass mortality of Artemia in mid-June practically in all shallow lakes. The mortality of brine shrimps was associated with laying by female adults of large amount of diapausing eggs which formed a harvestable stock on the shoreline in mid of summer, and there were 4 times more cyst in water column than in fall samples. It should be noted, however, that after the mass mortality of brine shrimp there was created favorable abiotic conditions up to the second decade of September that allowed the population to recover their resources. This is evidenced by the fact that in some lakes brine shrimp biomass in September is higher than in June (see Fig. 56). The recrutment of population, perhaps, can be explained by nauplii that hatch from "thinshell" cysts which are more resistant to the ambient conditions. Thus, the number of nauplii showed a twofold decrease during the period of mass mortality of brine shrimps.

The climatic conditions of the following three years were distinguished by moderately warm and high precipitation conditions, which caused an increase in the water level and a decrease in salinity. The oxygen regime was relatively favorable, and the temperature did not exceed the critical values for Artemia. The seasonal dynamics had a single or double hump character with some decline in biomass in August. No massive deposit of cysts in summer was observed.

The analysis for productivity level of lakes in various years showed that in relatively dry years of 2000 and 2001, the number of planktonic cysts and brine shrimp biomass was higher than 1.5 times in comparison with the years of 2002–2004. The maximum number of benthic cysts was registered in 2001 and 2002, and the maximum density of brine shrimp in 2001.

4.3. Mathematical modeling of Artemia population

4.3.1. Seasonal dynamics modeling of population density

A typical Artemia population, which exists, as a rule, without predators and food competitors, was taken for the analyses.

The mean density data on the Artemia population of various age classes (nauplii, meta-nauplii, juveniles, pre-adults, adults) was used to build the model. The averaged curve was built by dividing all the available data by the periods ranging from 1st to 14th and 15th to 30th dates of each month, and by finding the arithmetic mean for each period. As a result, the data presented in Tab. 22 was obtained. The curves of the density dynamics of various age classes of Artemia brine shrimp were built based on this data. Thus, it is necessary to find a model for the density that best suits both the direction of these curves, and the total average density for the whole season. For this purpose, a Leslie matrix model was selected (Williamson, 1975; Jeffers, 1981). The following representations were made for model-building:

— the Artemia population has 3–4 generations with prolonged period of reproduction during the season;

— a change in the number of this population occurs simultanesly both as a result of the brine shrimp transition from one age class to another, and the increase in the density due to live births, and its decrease due to death of individuals;

— the growing season begins in mid-April and ends in mid-October and is 180 days;

— every 7–8 days there is a transition from one age stage to another;

— sexual maturity is reached at 35 days for spring generation and it is 28 days for summer generation;

— the survival rate of nauplii to metanauplius stage is 20 %, it is 50 % from metanauplius stage to juvenile, it is 80 % from juvenile to pre-adults and from pre-adults to adults, the survival rate of adults from brood to brood is 50 %;

— brood every 7–8 days;

— ovoviviparous reproduction mode (nauplii + eggs) — 5 ind./brood (taking into account hatching of nauplii from eggs), oviparous — 15 cysts/brood.

Some of the representations have beed changed and simplified for this model:

— sexual maturnity onset for all generations is 4 weeks after birth of nauplius (28 days);

— there is no fixed life expectancy of brine shrimp, but the gradual withering away of adults.

Table 22. **Average long-term number of different Artemia age stages in some periods of a season, ind./l**

Periods of a season (date)	Nauplii and metanauplius	Juvenile	Pre-adult	Adult
April 16–30	329.71	0.00	0.00	0.00
May 1–15	65.42	0.25	0.02	0.00
16–31	26.57	25.25	2.64	0.06
June 1–15	57.57	6.32	6.71	4.55
16–30	11.50	3.65	6.63	2.32
July 1–15	7.84	0.50	5.70	5.27
16–31	42.94	1.44	7.07	8.09
August 1–15	6.98	0.35	0.69	0.84
16–31	1.01	0.19	0.58	1.58
September 1–15	1.04	0.19	0.43	3.12
16–30	3.10	0.05	0.77	3.11
October 1–15	0.15	0.01	0.19	0.40
M_{season}	**46.2**	**3.2**	**2.6**	**2.4**

The Leslie matrix for the Artemia population has the following form based on the above and long-term average values:

$$A=\begin{pmatrix} 0 & 0 & 0 & 0 & 5 \\ 0.2 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0.8 & 0 & 0 \\ 0 & 0 & 0 & 0.8 & 0.5 \end{pmatrix}.$$

Column vector a_{t0} representing the age structure of the population in the initial period is as follows:

$$a_{t0}=\begin{pmatrix} 330 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}.$$

The step by step calculation (with a step size of 1 week) is shown in Fig. 59. The graph of the seasonal dynamics of the Artemia population, which is similar to the above graph of long-term average density values dynamis, was built based on this data. A more detailed comparison (Fig. 60) showed some divergence in the dynamics.

The matrix well describes the dynamics of nauplii and metanauplius density. Peaks and drops, substantially, coincide both in time and in value.

In regard with other age classes, the matrix gives a curve which is one step (a week) ahead of the first peak observed in the natural conditions. Furthermore, the maximal value in natural condition is higher for juvenile stages and it is lower for adults and pre-adults. In general, the average seasonal values of various brine shimp age stages density are similar (see Fig. 59 and Tab. 22).

According to the matrix presented, 6.4 % of brine shrimp reach maturity. This figure is lower than the arithmetic mean for the populations investigated in model lakes (see Sect. 4.2.3), but matches with the nauplii density and survivability dependences found (see Fig. 57).

The data on females producing five broods per season was used for outling the periods of generetaion (see Sect. 4.1), as a result, the maximum conditional lifespan of each Artemia generation is 70 days. According to the scheme (see Fig. 59), the first generation of brine shrimp begins in April and ends in early July, the lifespan of the second generation is from early June to mid-August, and it is from the first decade of June to late September for the third generation. The brine shrimps of the fourth generation appear in mid-August, and there might appear mature adults in late September due to warm weather. Three generations of brine shrimp at the same time can be met in the first decade of July (1, 2 and 3 generations) and in mid-August (2, 3 and 4 generation).

During the season, in addition to the viviparious reproduction mode, there occur egg laying and they accumulatie on the lake. The number of cysts in the pond is obtained as of a certain date, and at the end of the season by multiplying the number of mature females by the number of cysts in each brood (see Fig. 59). The average number of cysts per season, calculated by the matrix, is close to the average values of population.

Thus, the construction of a mathematical model of seasonal population dynamics allowed us to conclude that our ideas of Artemia production is correct.

4.3.2. The estimated dynamical characteristics of the population

To calculate the dynamic characteristics of the population (survival, fecundity, mortality, lifespan, the duration of generation) we used the methodology presented in works of A.M. Gilyarov (1990).

The fecundity is defined as the number of individuals born in the population per unit of time. Since Artemia is reproduced by both viviparity and oviparity modes, we were interested in the fecundity both as a whole and separately for nauplii and eggs (offsprings that increase the population of the season) and cysts (offsprings that form the population of the next season).

Growth stage	April	May			June				July				August				September				October				Mean
	22	1	7	15	22	1	7	15	22	1	7	15	22	1	7	15	22	1	7	15	22	1	7	15	22	
Nauplii	330.0	0.0	0.0	0.0	0.0	105.6	52.8	26.4	13.2	6.6	37.1	35.5	26.2	17.3	10.8	17.3	20.0	18.4	14.7	10.8	10.9	11.9	11.8		33.8
Metanauplii	0.0	66.0	0.0	0.0	0.0	0.0	21.1	10.6	5.3	2.6	1.3	7.4	7.1	5.2	3.5	2.2	3.5	4.0	3.7	2.9	2.2	2.2	2.4		6.7
Juvenile	0.0	0.0	33.0	0.0	0.0	0.0	0.0	10.6	5.3	2.6	1.3	0.7	3.7	3.6	2.6	1.7	1.1	1.7	2.0	1.8	1.5	1.1	1.1		3.3
Pre-adult	0.0	0.0	0.0	26.4	0.0	0.0	0.0	0.0	8.5	4.2	2.1	1.1	0.5	3.0	2.8	2.1	1.4	0.9	1.4	1.6	1.5	1.2	0.9		2.6
Adult	0.0	0.0	0.0	0.0	21.1	10.6	5.3	2.6	1.3	7.4	7.1	5,.2	3.5	2.2	3.5	4.0	3.7	2.9	2.2	2.2	2.4	2.4	2.1		4.0
Cysts					317	158	79	40	20	111	106	78	52	32	52	60	55	44	32	33	36	35	32		987
Accumulation of cysts in the population						475	554	594	614	725	831	910	962	994	1046	1106	1161	1205	1249	1282	1317	1353	1385		

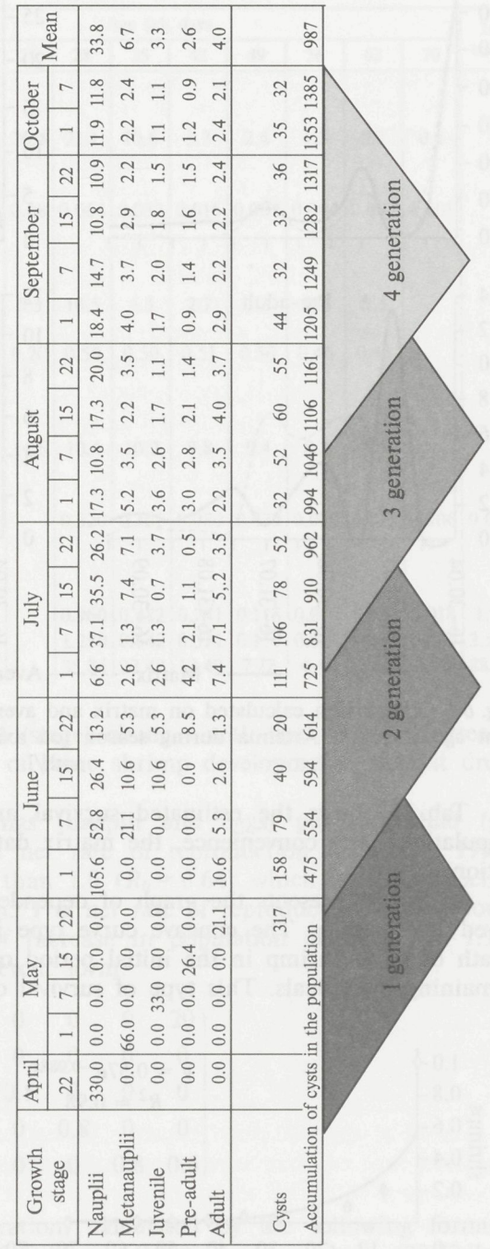


Fig. 59. Seasonal number of Artemia population (ind./l) calculated by the matrix.

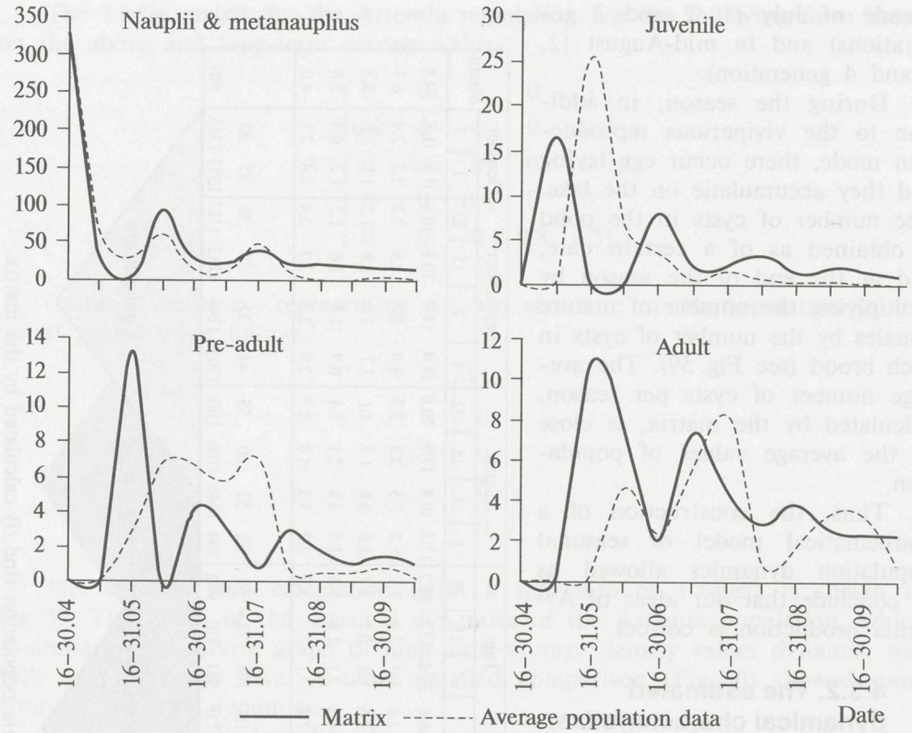


Fig. 60. Comparison calculated on matrix and average-population data of number of different age stages of Artemia during season (on axis abscissa — the period of researches), ind./l.

Tab. 23 shows the estimated survival and fecundity rates for the Artemia populations. For convenience, the matrix data was used only for the first generation.

In Fig. 61 presents the graph of dependencies of portions of individuals survived l_x on age x. The concave curve type in the first stage indicates the mass death of brine shrimp in the initial period of life and relatively low mortality of remaining individuals. This type of survival curve is widely distributed in natural conditions and, according to the researches by A.M. Gilyarov (1990), is characteristic of planktonic organisms with high fertility and lack of care for offsprings.

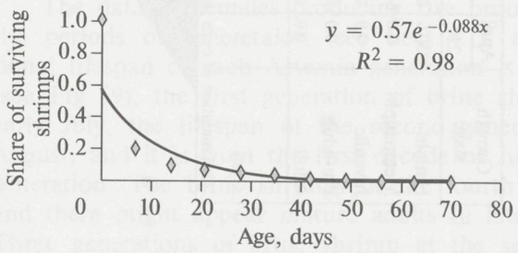


Fig. 61. Curve of survival of Artemia population.

The expected lifespan of individuals which survived until the

Table 23. **Calculated indicators of survival and birth rate for Artemia populations on example of the 1st generation**

Index	Age (x), days											In total
	0	7	14	21	28	35	42	49	56	63	70	
Number of live individuals at the moment accounting (nx)	330	66	33	26.4	21.1	10.6	5.3	2.6	1.3	0.7	0.4	
Proportion of individuals surviving to the beginning of the age interval x (lx)	1	0.2	0.1	0.08	0.064	0.032	0.016	0.008	0.004	0.002	0.001	
Number of individuals who have died from the beginning of the interval x before the interval $x+7$ (dx)	264	33	6.6	5.3	10.5	5.3	2.7	1.3	0.6	0.3		
Mortality in the interval x (qx)	0.80	0.50	0.20	0.20	0.50	0.50	0.51	0.50	0.46	0.43		
Life expectancy of individuals surviving to the beginning of the interval (ex), days	7.0	14.2	18.0	14.6	10.4	10.2	9.8	9.4	8.3	5.5		
Number of nauplii (m_x) born individuals who lived to the age interval ($5 \cdot l_x$)					0.320	0.161	0.080	0.039	0.020	0.011	0.006	0.637
Number of cysts (M_x) obtained from individuals who lived to the age interval ($15 \cdot l_x$)					0.960	0.482	0.241	0.118	0.059	0.032	0.018	1.91
$M_x + m_x$					1.280	0.642	0.321	0.158	0.079	0.042	0.024	2.547
$(M_x + m_x)x$					35.84	22.48	13.49	7.72	4.41	2.67	1.70	88.32

beginning of the next time interval (stage) changes with age: first, it increases from 7 to 18 days (juvenile stages of brine shrimp development), then it drops to 5.5 (see Tab. 23).

The indicators of live offsprings (nauplii and eggs) per individual (see Tab. 23) was used to estimate the net rate of reproduction (Gilyarov, 1990). This figure turned out to be less than 1.0 ($R_0 = 0.64$) which indicates decline in population within one generation. The net rate of reproduction with account of cysts to be laid is indicitave of increase in population density ($R_0 = 1.91$), and the matrix Leslie gains a different form:

$$B = \begin{pmatrix} 0 & 0 & 0 & 0 & 20 \\ 0.2 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0.8 & 0 & 0 \\ 0 & 0 & 0 & 0.8 & 0.5 \end{pmatrix}.$$

The average duration of generation, calculated by the following formula, according to the method by A.M. Gilyarov (1990) was equal to (88.32/1.91) 46.2 days.

$$T = \frac{\sum_{x=1}^{\infty} (M_x + m_x) \cdot x}{R_0},$$

determination of indicators M_x, m_x, x — given in Tab. 23.

The approximate values of the generation time (43.12 days) were obtained for the Altai Artemia populations (Solovov, Studenikina, 1990).

The growth rate of the Artemia populations can be determined by the more visual way. The Fig. 59 shows the dynamics of mature individuals of the first generation. We can obtain the number of all produced offsprings by multiplying the number matured individuals by clutch value. This value will make up 2.52 (cysts — 1.89, nauplii — 0.63) in recalculation per individual. Therefore, the specific growth rate of the *Artemia* population density ($r = ln\ R_0/T = 0.92/46.2$) will be equal to 0.02 per day. These values appeared to be 2-fold lower than the Artemia grown under the experimental conditions (Golubev, 2004). This fact is known for other organisms as well (Fenchel, 1974), and can be explained by the inhibiting effect of the environment pressure.

A relatively long period of maturing and low rate of growth of the Artemia population is probably due to the fact that in the presence of competing species of Artemia in the diet, as a rule, they are generally depressed. The same fact is noted in the work of Ya. Nimura (Nimura, 1987). However, the author took a very high fecundity (1320–1920 offsprings per female) in the calculation, which is probably, under the optimal culture conditions, but, as shown by our study, it is unlikely to happen under the natural conditions. The maximum number of offsprings produced by individual female (with the lifespan of up to 70 days) is 100 ind. In extremely rare cases, there are up to 150 embryos in female ovisac.

4.3.3. Mathematical interpretation of possible catch portion of the resource

Artemia is a great commercial value, so it is very important to determine the amount of the possible catch of resources from the pond with no harm to the population. The similar studies were conducted on two lakes in the Altai area (Studenikina, 1991; Solovov, Studenikina, 1992). The authors mathematically justified the amount of Artemia cysts catch which is equal to 30 % for medium-sized and small lakes, and it is 60 % for large lakes. The authors did not take into account the mortality of mature females during their lifespan in their calculation, and used high, in our opinion, survival rate of nauplii.

In our calculation procedure there was used matrix B, as it reflects the number of offsprings produced (20 offsprings in one brood; 5 broods; total number offsprings — 100) per individual female in the example of one generation:

$$B = \begin{pmatrix} 0 & 0 & 0 & 0 & 100 \\ 0.2 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0.8 & 0 & 0 \\ 0 & 0 & 0 & 0.8 & 0.5 \end{pmatrix}.$$

A main eigenvalue (λ) and the corresponding to it an eigenvector of this matrix (a), calculated by means of an iterative method are equal to:

$\lambda = 1.57$,

$a = [1000,\ 200,\ 100,\ 80,\ 64,\ 2817]'$.

The resulting eigenvalue of the matrix indicates the population is able to grow.

The proportion of possible catch has been defined by the formula (Jeffers, 1981) using a main eigenvalue:

$$H = 100\left(\frac{\lambda - 1}{\lambda}\right) = 100\left(\frac{1.57 - 1}{1.57}\right) = 36.3,$$

where H — the proportion of individuals taken from the population, %.

The proportion of possible catch of the resource, as determined by an eigenvector has a similar value: $\lambda = \sqrt{2.817} = 1.68$, consequently, $H = 40.5$ %.

The data obtained was approximate to the data obtained by the researches in the Altay area, in spite of the different initial survival rates (Studenikina, 1991; Solovov, Studenikina, 1992). Therefore, we consider it is reasonable to use the value of 30–40 % for the product withdrawal, without any damage to the Artemia populations in shallow lakes.

For the purposes of precautions that is required in predictive studies (Babayan, 2000) and, given that, in determining the norms of withdrawal of other zooplankton species 30 % is usually used, we recommend to rely on this number in calculation of TAC of the Artemia biomass unless a thorough study have not been conducted yet. However, it should be noted that there are different opinions in regard of the proportion of catch of the Artemia cysts: from 25 to 75 % (Studenikina, 1986a, b, 1991; Solovov, Studenikina, 1990, 1992; Evstigneev et al., 1997).

4.4. Distribution of Artemia in lake

It is known in the literature that the distribution of Artemia in lakes occurs to a greater extent due to the hydrological factors such as water temperature, salinity fluctuation, lighting, mixing of water (Oleinikova, 1972) and to a lesser extent — due to the nutritional factors (Makarov, 1984). Lake morphometry, namely the shape of basin, should be critical in distribution of Artemia. According to the studies by V.P. Solovov and T.L. Studenikina (1990), both in relatively deep lake Bolshoye Yarovoye and in shallow lake Solenoye, there was observed concentration of nauplii and younger age classes in the coastal and shallow areas of the lake throughout the growing season.

In summer and autumn, the number of matured brine shrimp is higher in the open area nearby the center. Meanwhile, the number of cysts and matured individuals in the surface layer of brine may vary more than 10 times, to a lesser extent the number of nauplii changes. The differences in distribution of Artemia in these lakes is that adult organisms locate at the bottom only in littoral area in the lake Bolshoye Yarovoye and prefer to inhabit in a layer of

10–100 cm in other parts, but in shallow lakes adults prefer to inhabit at the bottom, forming clusters in uneven ground. Probably, this scheme is good for all salt lakes in Western Siberia, in which, due to shallowness of most reservoirs, the hydrological conditions are of particular importance. It should be emphasized that the characteristics of brine shrimp and cysts distribution are critical when making representative measure of TAC.

Below is the example of the water area of three lakes in Kurgan region that show the features of the horizontal distribution of brine shrimp (App. 34, 35).

The analysis of cysts, nauplii and brine shrimp distribution allowed us to make some important conclusions for determination of TAC.

Firstly, the distribution of all age classes of Artemia in plankton of lakes, basically, is very uneven. The ratio value of maximum number of individuals to mean ($N_{max}/\bar{N}$) are in the range from 1.0 to 3.0 with an average of 1.83 for cysts, 1.96 for nauplii and 1.94 for brine shrimp for all lakes. As an indicator of distribution of individuals in the population there was used the ratio of the variance to the mean number of density (Odum, 1986). The indicator of organism distribution (D) widely fluctuated: for cysts — from 0.43 to 6442 with an average of 660, for nauplii — from 0.4 to 653 with an average of 120, for brine shrimp — from 0.06 to 205 with an average of 18. Cysts were uniformly distributed in lakes ($D < 1$) in 3.6 % of cases, and nauplii — in 44 % of cases, brine shrimp — in 46 % of cases. From this it follows that the cysts are more capable of forming clusters than nauplii and brine shrimps. Such large values of the coefficient of variation (C_v) as: for cysts of an average of 88 % (fluctuation limits from 9 to 159), for nauplii an average of 108 % (fluctuation limits from 3 to 245), an average of 105 % for brine shrimp (fluctuation limits from 48 to 182), indicate the need for reasonable increase in sample size, in this case stations.

Second, the distribution of cysts and nauplii in spring, effect the accumulation of last year cysts. In parts where there were more of stocks of cysts, the number of cysts and hatched nauplii in April and May was higher.

Third, the distribution of cysts in summer and autumn is greatly influenced by the direction of the prevailing winds.

Fourth, the impact of food factor on the distribution of older age classes of brine shrimp (organisms that actively move and are able to choose habitats) could not be detected. The comparative analysis of phytoplankton biomass and brine shrimp from the same stations failed to reveal any patterns: Artemia was concentrated sometimes at stations with a higher phytoplankton density (possibly due to active movement of brine shrimp to places with the best food conditions), and sometimes at stations with less phytoplankton density (possibly because of phytoplankton grazing by Artemia).

The analysis of the vertical distribution of Artemia in shallow lakes with average depth of less than 2 m showed that mature brine shrimp prefer to inhabit near the bottom. The relatively uniform distribution by depth of adults was observed in lakes with an average depth of 2–3.5 m and alittle less uniform distribution of juveniles.

The vertical distribution of Artemia in the deep lake Bolshoye Yarovoye (Studenikina, Novoselov, 1998) is characterized by the aggregation of immature brine shrimp in the water column up to 2 m, mature brine shrimp were vertically distributed more evenly, but avoided coastal areas. The variability in plankton abundance of cysts was mostly insignificant.

In all types of lakes all age classes avoided to inhabit in the surface layer of 0–10 cm; but actively distribute all over the ephtrophic zone, preferring the layer of 10–200 cm, nauplii preferred upper layers of 10 to 40 cm from the surface.

Chapter 5

THE EFFECT OF DIFFERENT ENVIRONMENTAL FACTORS ON THE DEVELOPMENT AND PRODUCTIVITY OF ARTEMIA

5.1. The influence of some major biotic and abiotic factors

The factors influeincing the development of Artemia, are divided into:

— abiotic factors that include physical and chemical factors such as light, temperature, turbidity, water movement, weather conditions, the concentration of dissolved minerals, organic matter, content of gases, etc. and morphometric such as depth, lake area, shape of the basin, etc.;

— biotic factors that include food supply, parasitism, predation, and interspecies and intrapopulation competition, etc.;

— anthropogenic factors that include harvesting, water pollution, etc.

Artemia can exist only within a certain range of variability in specific environmental factors. The ecological valence of Artemia has been the most extensively studied with regard to temperature, salinity and oxygen (see Ch. 1). The effect of light on the vital functions of Artemia probably also may have a regulatory role. Thus, according to the research by P. Sorgeloos (Sorgeloos, 1979), photoperiod, i.e. the length of daylight is an environmental signal that blocks the release of nauplii from cysts. However, a clear dependence of time of nauplii hatching time the first generation on photoperiod was not marked; apparently, the light has an effect on reproduction of brine shrimp in conjunction with other factors, but first of all — with the water temperature and food avaibility.

The most extensively studied biotic factor is the influence of food supply and competition with other filter feeders. The specific influence of anthropogenic factors is not covered in the literature. However, it is believed that the decline in the Artemia stocks on Great Salt Lake (USA, Utah) was due to overharvesting of Artemia cysts.

The optimal and critical value of a variety of factors, as is well — known, do not have harsh values and can vary as a result of adaptation to certain environmental conditions.

Such studies have not been conducted under the conditions of Western Siberia, so it was interesting to identify the most important factors influencing the Artemia population and their trend.

15 indicators were distinguished out of all listed above variety of factors that determine, in our opinion, the quantitative population development of Artemia. These are salinity, acidity, chloride, sulfate, chloride to sulphate ratio,

zooplankton biomass, species diversity of zooplankton, phytoplankton biomass, Artemia biomass, Artemia population, the number of planktonic and benthic cysts, number of cysts, eggs and nauplii in female ovisac.

In the waters of the Siberian region, the temperature is a main factor of seasonal development of the Artemia populations and their vegetation is limited by intervals from 4–5 °C up to 38 °C. To neutralize the effect of seasonal variations in temperature, there were used the average values of all parameters for season for the analysis.

The analysis was performed in two options:

— first — on long-term average data from 30 lakes: $n = 30$ (App. 36);

— the second — on all available mean seasonal data: $n = 144$ (App. 37).

Such indicators as the content in water of dissolved oxygen, mineral nitrogen, phosphate, iron, diameter of cysts, a weight of mature females of Artemia were excluded from the analyses. These numbers generally are in weak unreliable relationship with other parameters.

The following indicators were analyzed in the first and second (in brackets) options: water salinity from 41 to 222 g/l (30–288), pH — from 7.6 to 9.1 (7.1–9.2) chloride content from 19.7 to 96 g/l (14–141), sulphates — from 3 to 57 g/l (1–92), zooplankton biomass — from 0 to 8.3 mg/l (0–23), number of zooplankton species — from 1 to 4 (1–6), phytoplankton biomass — from 0.02 to 6.0 mg/l (0.01–16.6), Artemia biomass — from 1.2 to 61.3 mg/l (0–181), number of Artemia brine shrimp — from 2.4 to 211 ind./l (0–960), number of planktonic cyst — from 2.3 to 340 ind./l (0–801), benthic cysts — from 0 to 2369 thousand ind./m^2 (0–7165), specific number of cysts in Artemia female ovisac — from 0 to 28.4 (0–75), eggs — from 0.9 to 51.6 (0–62), nauplii — from 0 to 2.2 (0–4.4) in female ovisac.

In the first option, the coefficients of linear correlation between 15 parameters appeared to be reliable in 53 cases (25 %) and with the non-parametric Spearman correlation — in 75 cases (36 %). Thus, approximately half of correlations were reliable ($r > 0.5$).

In the second option, the coefficients of linear correlation between 15 parameters were reliable in 74 cases (35 %) and with the non-parametric Spearman correlation in 98 cases (47 %) (App. 38, 39). Moreover, about a quarter of correlations were reliable ($r > 0.5$).

App. 40 and 41 show a direction and magnitude of vectors of coefficients of reliable correlations of linear and non-parametric relationships for the first and second options.

According to the analysis conducted in two ways, the zooplankton biomass (without including Artemia) was positively correlated with the number of zooplankton species and negatively with salinity of the environment, namely, with the content of chlorides and sulfates. There was also a negative dependency between the number of zooplankton species and salinity, chlorides and sulfates, as well as with indicators of the Artemia population density (biomass and abundance of Artemia brine shrimp and cysts). The phytoplankton biomass were positively correlated with water salinity (mainly chlorides) and negatively with pH value from the abiotic factors, and from biotic factors were negatively

correlated with the number of zooplankton species and positively with the main indicators of the Artemia population density.

There was a significant positive relationship between the number and biomass of Artemia brine shrimp, that's why the direction of the vectors and their magnitude, were largely, similar.

The biomass and number of brine shrimp from abiotic factors experienced a positive effect of salinity and chlorides, less effect of sulfates and negative effect of acidity. With such biotic factors as biomass and number of zooplankton species, the biomass and abundance of Artemia were in opposite dependency, and were in positive dependency with the phytoplankton biomass, number of planktonic and benthic cysts, a specific number of nauplii in ovisac.

The direction and magnitude of the vectors of the correlation coefficients between 15 parameters and the number of planktonic and benthic cysts in most cases were the same: a positive correlatoin was observed for salinity, chlorides, sulfates, the Artemia population densities, specific number of cysts in ovisac, and there was a negative corellation with pH values and number of zooplankton species in some cases.

There was observed a positive relationship between the specific number of cysts in ovisac and nauplii in ovisac and salinity, chlorides, sulfates. The number of nauplii in ovisac was in a negative relationship with pH values, and there was a positive relationship with indicators of density of the Artemia community.

The specific number of cysts and eggs in ovisac was in antiphase. The number of eggs in ovisac was a negative relationship with indicators of environmental salinity.

Thus, in biotope of hypersaline lakes, all production processes are influenced by water salinity. Our studies have shown a positive effect of salinity on the Artemia population density (biomass and abundance of brine shrimp; the number of planktonic and benthic cysts, the number of cysts and nauplii in ovisac) and negative effect on the density and diversity of other zooplankton species and number of eggs per Artemia female ovisac. There were calculated partial correlation coefficients in order to neutralize the effect of salinity and find out the relationship between factors (Lakin, 1990).

It was found out that in elimination of salinity effect on some relationships have disappeared, while others appeared (App. 42).

Thus, if to take into account both partial and paired correlation coefficients (see App. 38, 39, 42), we can state the following:

— the value of Artemia biomass population is closely related to the chloride content;

— there is a strong positive relationship between the number of planktonic and benthic cysts;

— the number of eggs per female ovisac as well as an abundance of other zooplankton species is in antiphase with water salinity;

— the number of brine shrimp in population is determined by the number of nauplii in ovisac.

The latter proves once again that the recruitment of the population occurs due to viviparity reproduction. The lack of relationship between the number of eggs in ovisac and population number doubt in direct participation of eggs in population recruitment. Perhaps, hatching of eggs in natural environment under laboratory culture does not occur immediately, as noted by some authors (Golubev, 2004) but after longer time.

5.2. Effect of salinity on the reproductive traits of Artemia

Artemia is related to hypersaline brine shrimp that can grow well in natural marine waters, but because of the lack of any anatomical defense mechanism against predators, they can become an easy prey for carnivores (fish, crustaceans, insects, etc.). However, due to physiological adaptation to biotopes with high salinity, Artemia acquired an effective ecological environmental defense mechanism against predators. Artemia has the most effective osmoregulatory system, which is known in the animal kingdom (Croghan, 1958). Therefore, where Artemia is thriving, there predators can not survive.

It is known from the literature (see Ch. 1) that the effect of salinity on Artemia is ambiguous. Different ranges of salinity have different effects on the entire cycle of Artemia development from cysts to adult organism. Therefore, the attempt was made to analyze the effect of water salinity on individual parameters of Artemia productivity. The following 3 options of data were used for analysis:

1) average long-term data on lakes investigated the most extensively (sampling for different indicators from 25 to 42);

2) seasonal mean data for all populations studied (selection for different indicators from 90 to 144);

3) all data on a certain date for all lakes (sampling for different indicators from 273 to 514).

5.2.1. Salinity and weight of Artemia brine shrimp

There was found a weak reliable negative relationship between the weight of mature females of Artemia and water salinity (Fig. 62) and a linear correlation coefficient $r = -0.17$, -0.22, -0.47 respectively for all data available on lakes on a certain date ($n = 305$); for seasonal values ($n = 122$) and population data ($n = 42$). This once again confirms that when salinity increases at relatively unchanging body length of brine shrimp (see Sect. 3.1.2.2), their oblongness increases.

5.2.2. Salinity and Artemia fertility

Artemia brine shrimp propagate in a wide range of salinity from 20 to 260 ‰ (see Tab. 1). The optimum limit, according to many authors, are in amplitude from 30 to 170 ‰ in laboratory cultivation, and it is from 60 to 200 ‰ under the natural conditions. The optimum for viviparity reproduction, as a rule, a little shifted towards lower salinity values (50–200 ‰ according to different authors) and it require high salinity for cyst formation (120–200 ‰).

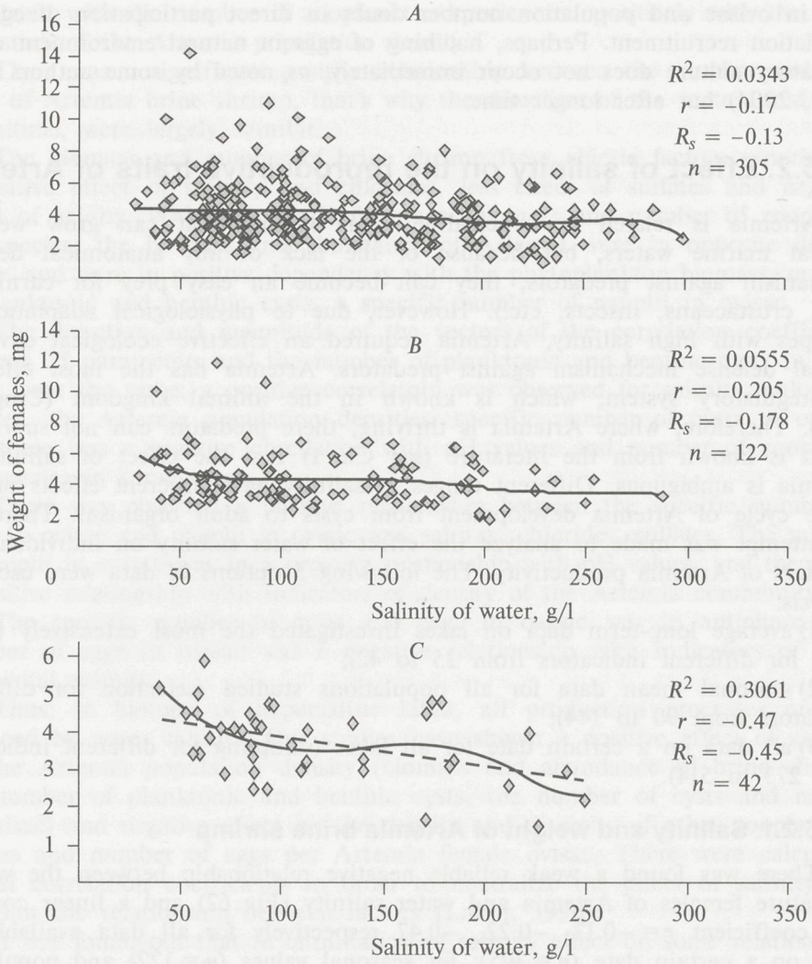


Fig. 62. Ratio between Artemia female weight and salinity.
A — all data; *B* — seasonal data; *C* — population data.

In our studies, all kinds of reproduction registered within a salinity of 30 to 300 g/l. As mentioned above, cyst and egg formation was in antiphase (Fig. 63). The analysis carried out on all the data available (on a separate date), seasonal (on average seasonal data) and on the average of 30 lakes (average long-term data) showed that the formation of cysts in the female ovisacs were in weak relationship with salinity in the range of 50 to 270 g/l. The specific

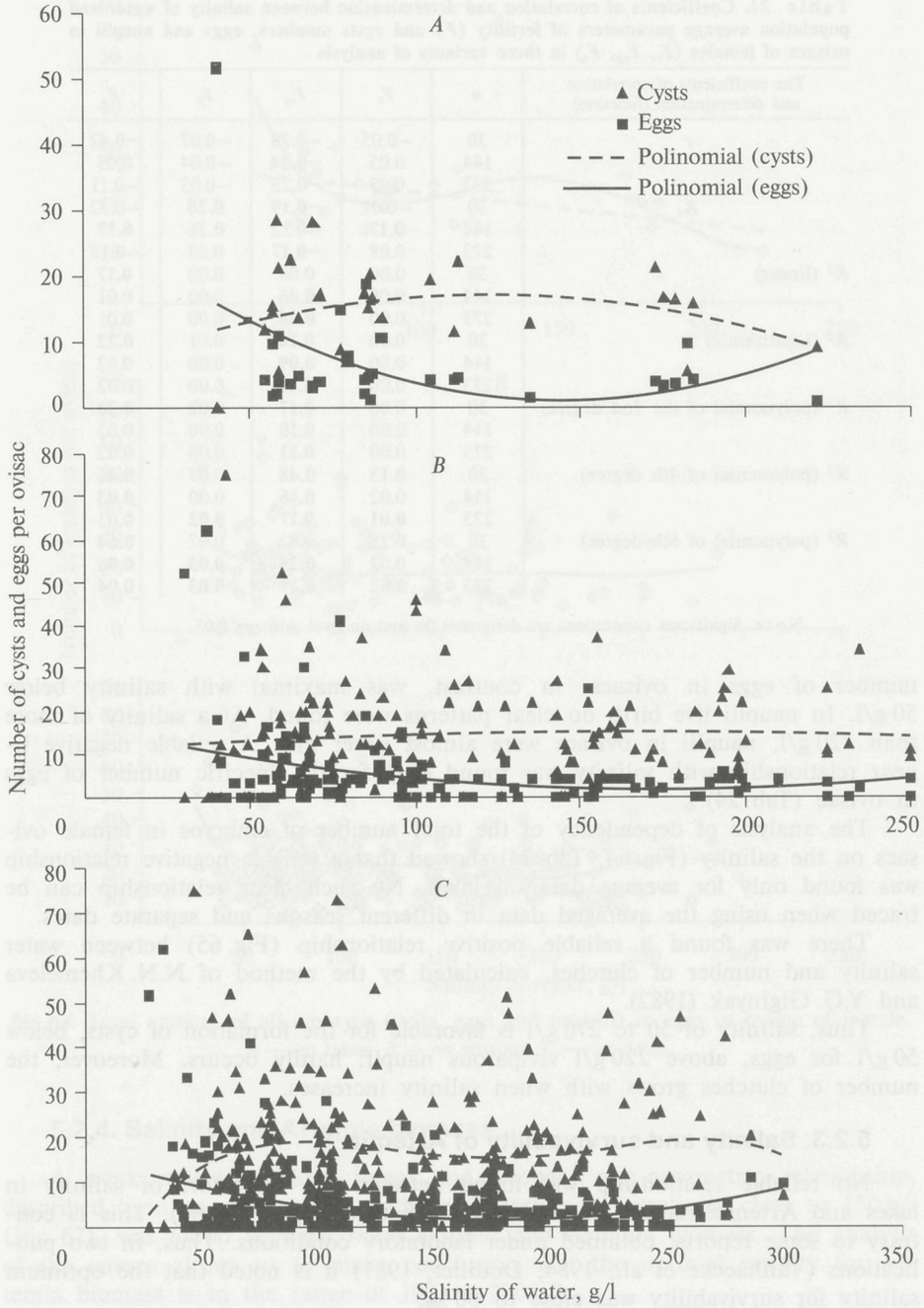


Fig. 63. Average population parameters of number of cysts and eggs in ovisac of Artemia female and salinity of water.
A — on lakes; *B* — on seasons; *C* — on dates.

Table 24. **Coefficients of correlation and determination between salinity of water and population average parameters of fertility (F) and cysts numbers, eggs and nauplii in ovisacs of females (F_c, F_{eg}, F_n) in three variants of analysis**

The coefficients of correlation and determination (function)	n	F_c	F_{eg}	F_n	F
r	30	−0.05	−0.29	−0.07	**−0.42**
	144	0.05	**−0.24**	−0.04	0.05
	273	0.03	**−0.25**	−0.03	−0.11
R_s	30	−0.01	**−0.19**	**0.20**	−0.32
	144	**0.17**	−0.12	**0.26**	**0.17**
	273	0.08	**−0.17**	0.03	−0.12
R^2 (linear)	30	0.00	0.08	0.00	**0.17**
	144	0.00	**0.06**	0.00	0.01
	273	0.00	**0.06**	0.00	0.01
R^2 (logarithmic)	30	0.00	**0.14**	0.01	**0.22**
	144	0.00	**0.09**	0.00	0.02
	273	0.00	**0.11**	0.00	0.02
R^2 (polynomial of the 2nd degree)	30	0.06	**0.17**	0.02	**0.20**
	144	0.00	**0.10**	0.00	0.02
	273	0.00	**0.11**	0.00	0.02
R^2 (polynomial of 4th degree)	30	**0.13**	**0.48**	0.03	**0.46**
	144	0.02	**0.16**	0.00	**0.03**
	273	**0.01**	**0.17**	**0.02**	0.03
R^2 (polynomial of 6th degree)	30	**0.25**	**0.82**	0.07	**0.64**
	144	0.02	**0.25**	**0.03**	**0.06**
	273	**0.02**	**0.19**	**0.03**	0.04

Note. Significant connections are designates fat font on level value $p < 0.05$.

number of eggs in ovisacs, in contrast, was maximal with salinity below 50 g/l. In nauplii live birth no clear patterns were found. At a salinity of more than 220 g/l, nauplii in ovisacs were almost never met. A reliable negative linear relationship with salinity was found only for the specific number of eggs in ovisac (Tab. 24).

The analysis of dependency of the total number of embryos in female ovisacs on the salinity (Fig. 64, Tab. 24) showed that a reliable negative relationship was found only for average data on lakes. No such clear relationship can be traced when using the averaged data in different seasons and separate dates.

There was found a reliable positive relationship (Fig. 65) between water salinity and number of clutches, calculated by the method of N.N. Khemeleva and Y.G. Giginyak (1982).

Thus, salinity of 50 to 270 g/l is favorable for the formation of cysts, below 50 g/l for eggs, above 220 g/l viviparous nauplii hardly occurs. Moreover, the number of clutches grows with when salinity increases.

5.2.3. Salinity and survivability of Artemia

No reliable relationship was found between the indicators of salinity in lakes and Artemia nauplii survivability to mature stage (Fig. 66). This is contrary to some reports, obtained under laboratory conditions. Thus, in two publications (Vanhaecke et al., 1984; Douillet, 1987) it is noted that the optimum salinity for survivability was close to 60 ‰.

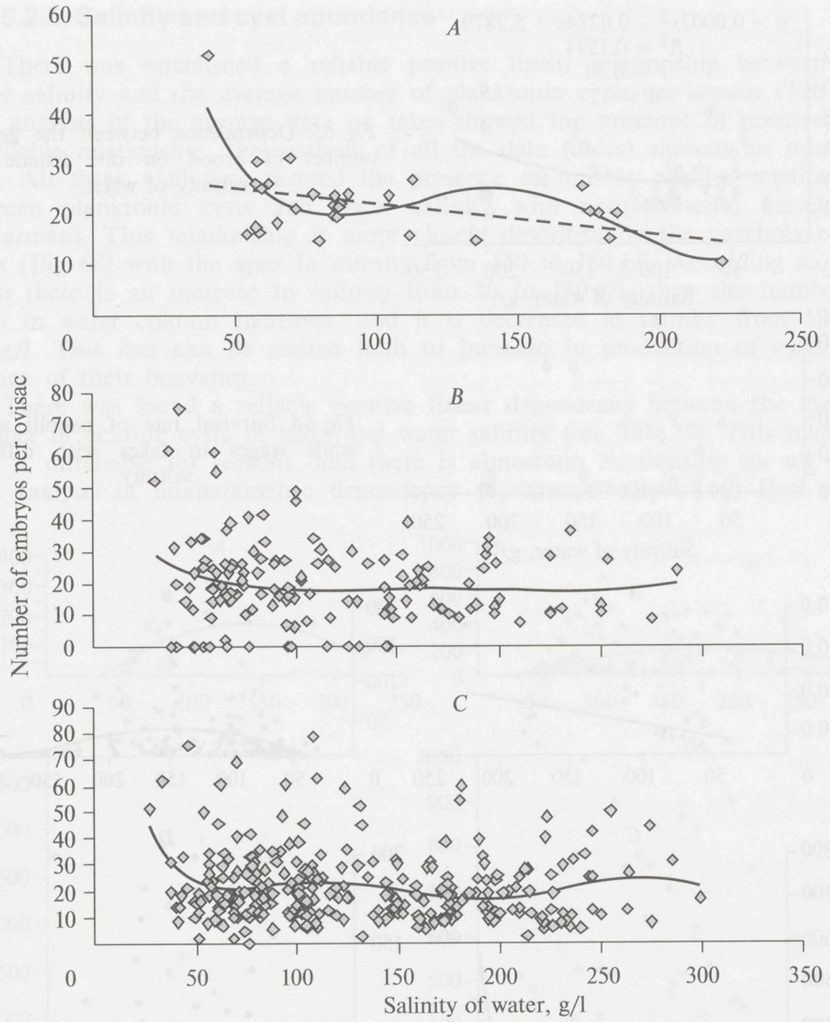


Fig. 64. Total amount of all embryos (cysts, eggs and nauplii) in eggs in ovisac of female. *A* — on lakes; *B* — on seasons; *C* — on dates.

5.2.4. Salinity and Artemia biomass

A weak reliable positive linear and stronger non-parametric relationship, described by a parabolic curve with an inflection at a salinity close to 150 g/l (Fig. 67), was found between water salinity and Artemia biomass. The analysis of the curves allows us to make conclusion that the optimal salinity for Artemia biomass is in the range of 100 to 200 g/l.

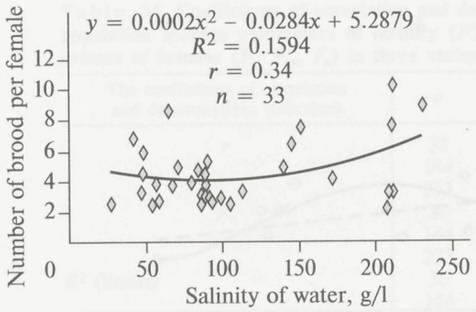


Fig. 65. Dependence between the general number of brood on one female and salinity of water.

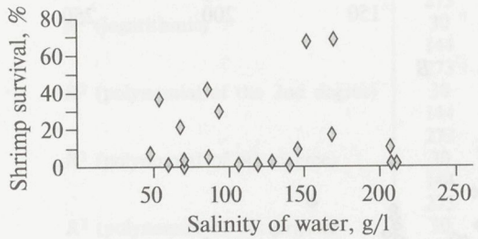


Fig. 66. Survival rate of nauplii up to adult stages in lakes with different salinity.

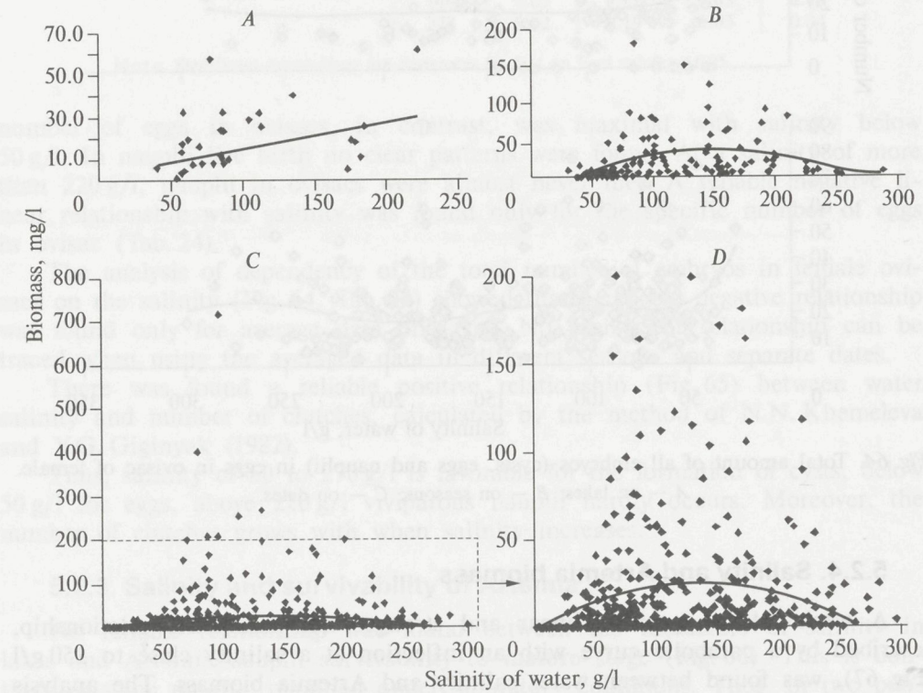


Fig. 67. Artemia shrimps biomass depending on salinity.
A — on lakes; *B* — on seasons; *C*, *D* — on dates (*D* — part of the picture *C*).

5.2.5. Salinity and cyst abundance

There was established a reliable positive linear relationship between the water salinity and the average number of planktonic cysts per season (Tab. 25). The analysis of the average data on lakes showed the presence of positive, but unreliable relationship, the analysis of all the data (dates) showed no relationship. All three analysises showed the presence of reliable positive relationship between planktonic cysts and water salinity with nonparametric correlation (Spearman). This relationship is more closely described by the parabola equations (Fig. 68) with the apex in salinity from 140 to 180 g/l. According to this, when there is an increase in salinity from 30 to 140 g/l, then the number of cysts in water column increases, and it is decreased at salinity from 180 to 300 g/l. This fact can be related both to increase in production of cysts and change of their buoyancy.

There was found a reliable positive linear dependency between the average number of benthic cysts in lakes and water salinity (see Tab. 25). This relationship is unreliable for seasons, and there is almost no relationship for all data. The analysis of nonparametric dependency (Spearman) allowed to find a re-

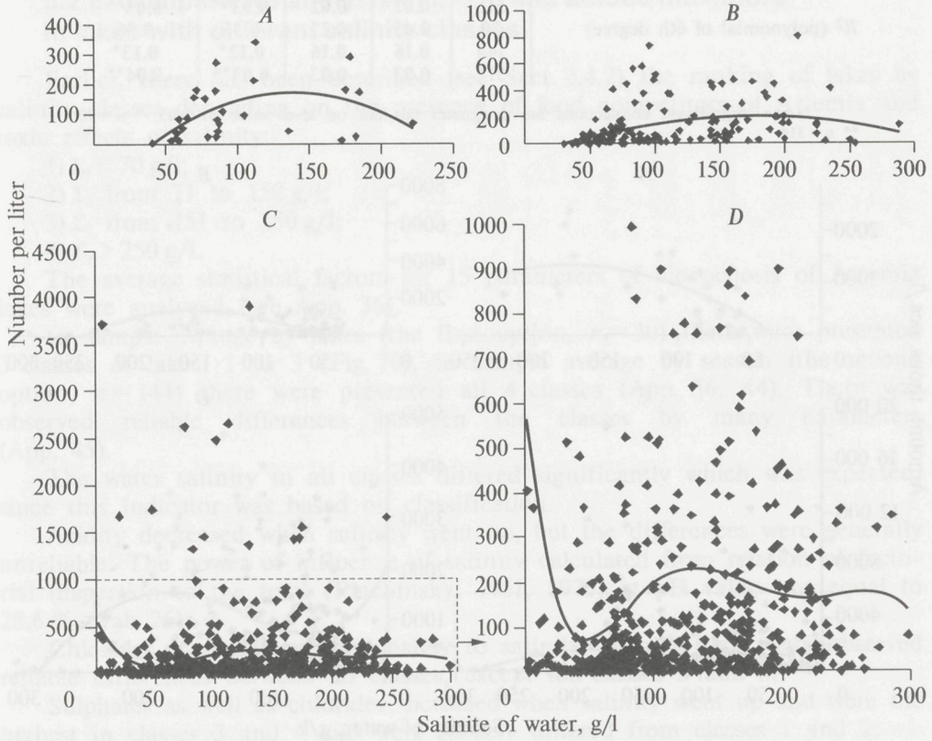


Fig. 68. Planktonic cysts number depending on salinity.
A — on lakes; *B* — on seasons; *C*, *D* — on dates (*D* — part of the picture *C*).

Table 25. **Coefficients of correlation and determination between salinity of water and biomass (*B*) of shrimps and number (*N*) of Artemia shrimps**

The coefficients of correlation and determination (function)	*n*	*B*	*N*		
			plank-tonic	benthic	planktonic and benthic
r	30	**0.38**	0.26	**0.48**	**0.48**
	144	**0.19**	**0.28**	0.16*	0.2*
	511	0.02	0.04	0.05**	0.06**
R_s	30	**0.45**	**0.42**	**0.52**	**0.54**
	144	**0.46**	**0.44**	**0.28***	**0.38***
	511	**0.12**	**0.24**	0.06**	0.07**
R^2 (linear)	30	**0.14**	0.07	**0.23**	**0.23**
	144	**0.04**	**0.08**	0.03*	0.04*
	511	0	0	0	0
R^2 (logarithmic)	30	**0.15**	0.11	**0.24**	**0.26**
	144	**0.07**	**0.1**	0.04*	**0.06***
	511	0	0	0	0
R^2 (polynomial of the 2nd degree)	30	**0.14**	**0.22**	**0.27**	**0.29**
	144	**0.14**	**0.12**	**0.09***	**0.11***
	51	**0.01**	0	0	0
R^2 (polynomial of 4th degree)	30	**0.43**	**0.23**	**0.32**	**0.33**
	144	**0.14**	**0.13**	**0.11***	**0.13***
	511	**0.02**	**0.02**	**0.03****	**0.03****
R^2 (polynomial of 6th degree)	30	**0.45**	**0.27**	**0.36**	**0.36**
	144	**0.16**	**0.16**	**0.12***	**0.13***
	511	**0.03**	**0.03**	**0.03****	0.04**

Note. Significant connections are designates fat font on level value $p < 0.05$; * $n = 90$; ** $n = 314$.

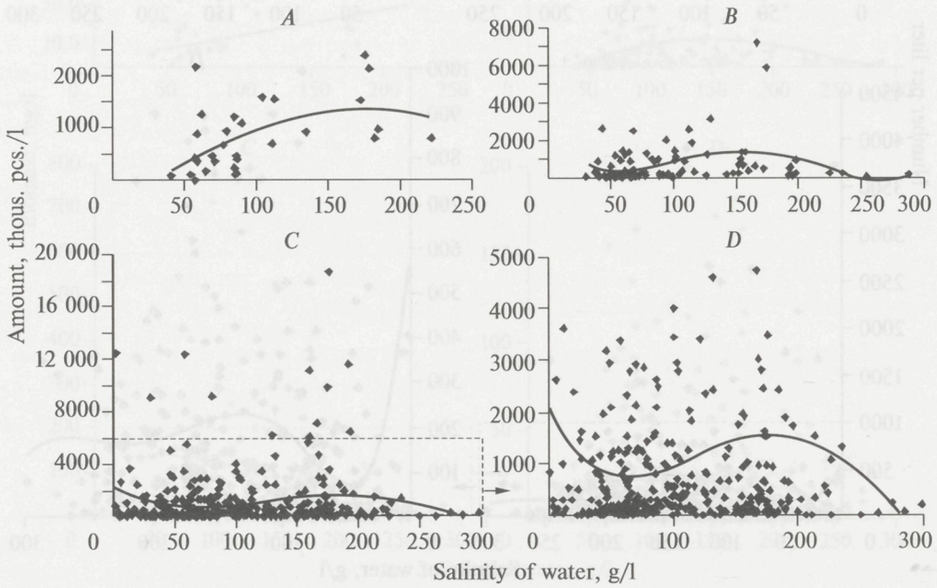


Fig. 69. Benthonic cysts number depending on salinity.
A — on lakes; *B* — on seasons; *C*, *D* — on dates (*D* — part of the picture *C*).

liable positive relationship for lakes and seasons, the analysis of all the data showed its absence. This dependency is more closely described by the equation of parabola (Fig. 69). Inflection of the curve shows that the maximum number of benthic cysts is observed at salinity within the range from 160 to 180 g/l. The decrease of cyst number nn the bottom at the salinity above 180 g/l may be due to better buoyancy of cysts at higher salinity.

The analysis of dependencies between the number of cysts in ecosystem (planktonic and benthic) and water salinity showed that all relationships are similar to benthic cysts dependencies (App. 43), because their portion in the community is the highest with an average of about 80 %.

Based on the stated above, we conclude that the analysis of the effect of salinity is better to conduct on average seasonal and average data for populations in which more than 80 % of the indicators showed a reliable relationship. In most cases (61 %) at the third row of data (by dates) the correlation was absent or unreliable.

Therefore, the further study the effect of salinity was carried out only for average values by populations and seasons.

5.2.6. Comparative analysis of biotic and abiotic indicators in lakes with different salinity classes

Earlier, there has been described (see Sect. 2.4.2) the ranking of lakes by salinity classes depending on the presence of food competitors of Artemia and toxic effects of salinity:

1) $\Sigma_i < 70$ g/l;
2) Σ_i from 71 to 150 g/l;
3) Σ_i from 151 to 250 g/l;
4) $\Sigma_i > 250$ g/l.

The average statistical factors for 15 parameters of biocoenosis of Artemia lakes were analyzed (see App. 36).

In sample average by lakes (the first option, $n = 30$) there were presented 3 classes of lakes: 1 to 3 (Fig. 70), in sample average by season (the second option, $n = 144$) there were presented all 4 classes (App. 36, 44). There was observed reliable differences between the classes by many parameters (App. 45).

The water salinity in all classes differed significantly which was expected, since this indicator was based on classification.

Acidity decreased when salinity went up, but the differences were generally unreliable. The power of influence of salinity calculated from relation of factorial dispersion to the total (Plochinsky, 1961, 1975) at pH value was equal to 28.6 % (Tab. 26).

Chlorides increased proportionately to salinity whereas there were observed reliable differences between all classes, except for classes 3 and 4.

Sulphates as well as chlorides increased when salinity went up and were the highest in classes 3 and 4 and were reliably differed from classes 1 and 2.

The relative value of Cl^-/SO_4^{2-} had unreliable differences between all classes.

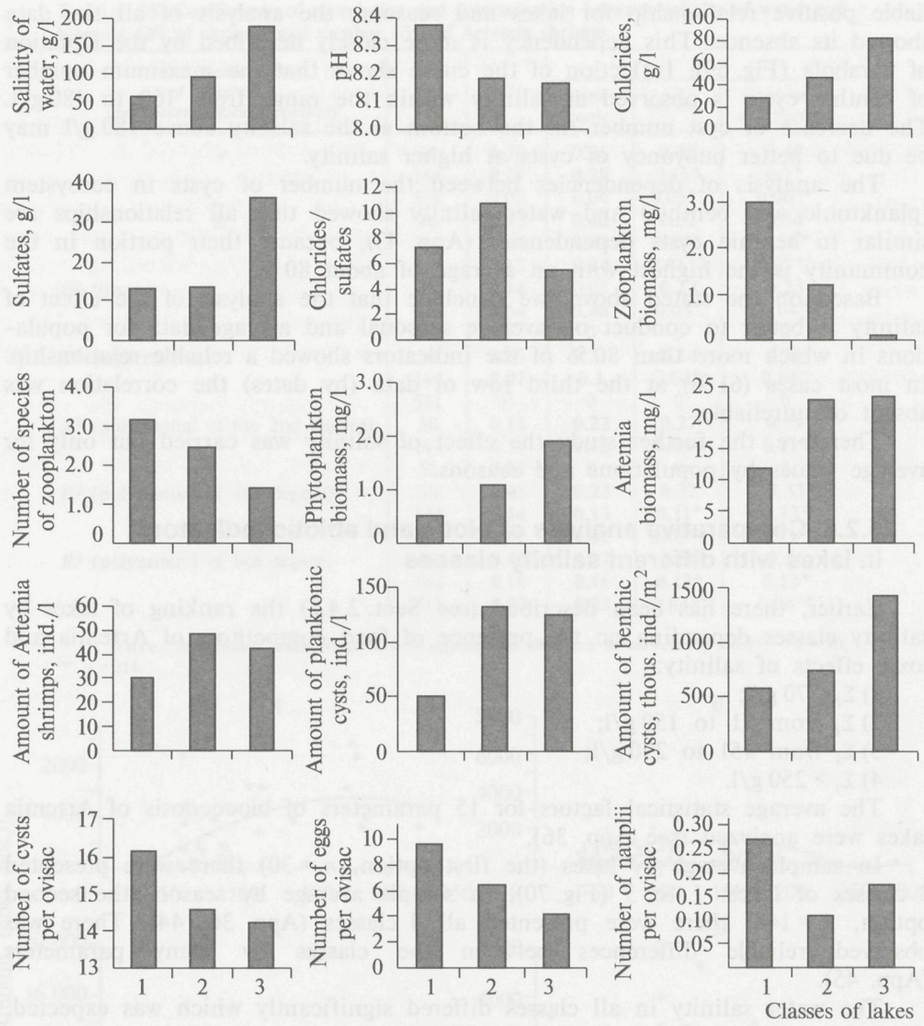


Fig. 70. Scheme of change of abiotic and biotic parameters in different classes of lakes ($n = 30$).

Consequently, when salinity grow, the content of chlorides and sulfates increases as well, but pH value lowers a little. The high influence power of salinity (see Tab. 26) on the hydrochemical indicators, except for the relative value of Cl^-/SO_4^{2-} can be explained by interconnection of these factors.

Biomass (excluding Artemia) and the number of zooplankton species in almost all classes decreased significantly when salinity increased. The zooplankton biomass by 16.1 % is conditioned by effect of salinity and the number of species — by 39.7 %.

Table 26. **Force of influence of salinity on some parameters of salt lakes biocenosis, %**

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Force of influence	**98.6**	**28.6**	**66.7**	**44.9**	3.7	**16.1**	**39.7**	3.3	**16.6**	2.7	**11.7**	6.5	0.5	4.7	0.2

Note. 1 — Σ_i; 2 — pH; 3 — Cl^-; 4 — SO_4^{2-}; 5 — Cl^-/SO_4^{2-}; 6 — *B* zooplankton; 7 — number of zooplankton species; 8 — *B* phytoplankton; 9 — *B* Artemia; 10 — *N* Artemia shrimps; 11 — *N* planktonic cysts; 12 — *N* benthonic cysts; 13 — F_c, 14 — F_{eg}, 15 — F_n. Significant value is designated the fat font at a $p < 0.01$.

The phytoplankton biomass had no significant difference in the classes of a large sample ($n = 144$) and was significantly lower than in class 1, as compared with class 3 in a small sample ($n = 30$). The influence power of salinity on phytoplankton biomass is negligible and made up 3.3 %.

The Artemia biomass was the highest in classes 2 and 3, however, where $n = 30$, the differences appeared to be insignificant. Where $n = 144$ Artemia biomass in class 2 was maximal in class 3 — a little lower. The differences between classes 2 and 3 are insignificant, but significant between classes 2, 3 and 1. The power of influences of salinity on Artemia biomass was 16.6 %.

The differences in number of brine shrimp in all classes were unreliable. The power of influence of salinity on this indicator was 2.7 %.

The different indicators of influence power of salinity on abundance and biomass of brine shrimp, probably, can be explained by the fact that the brine shrimp number is based on nauplii, and for their hatching from cysts high salinity level is not required. The Artemia biomass is based upon elder age classes, and for their growth and development (as well as for co-existence with the species-competitors) a higher salinity is required.

The number of planktonic cyst is maximal in classes 2 and 3, and is significantly different from class 1. The power of influence is equal to 11.7 %.

The benthic cysts number is maximal in class 3, but the difference was not reliable with a large sample, where $n = 30$ this indicator in class 3 is significantly higher than in classes 1 and 2. The power of influence of salinity is 6.5 %.

The specific number of cysts, eggs, nauplii in female ovisacs in all classes had unreliable differences, where the power of influence of salinity was 0.5, 4.7 and 0.2 %, respectively.

The studies have shown that the Artemia population density (biomass and abundance of brine shrimp, planktonic cyst abundance) is maximal in classes 2 and 3 at a salinity of 70 to 250 g/l. The number of benthic cysts is maximal in class 3 lakes at a salinity of 150–250 g/l. Since the bulk of the cyst is at the bottom, then the total number of cysts in the population is the largest in the class 3. As brine shrimp fertility is a little affected by salinity, then it is likely that the high number of cysts in the population occur due to increase in density of the Artemia population and the number of clutches when salinity goes up.

Thus, an increase in water salinity of lakes:

— Reduces the individual body weight of adult brine shrimp;

— Does not affect on number of offsprings per brood, but leads to reduction of viviparity reproduction, including reduction in number of eggs per brood;

— Increases the number of broods;
— No effect on survival of brine shrimp;
— Increases the number of cysts in the plankton and benthos.

The analysis of our data showed that the density of the Siberian Artemia populations is greatest at salinity close to 150 ‰, and cysts production at salinity close to 150–180 ‰. Our data obtained in the analysis of field studies are close to salinity limits obtained in laboratory: 100–170 ‰ — for growth and survival, 120–200 ‰ — for the production of cysts (Wear, Haslett, 1987). However, they are a little above the limits described for the natural biotopes: 130–170 ‰ — for the production of cysts (Perez Rodriguez, 1987), 90–150 ‰ — for of biomass and production cysts (Bhargava et al., 1987). A wider range of optimum (100–180 ‰) for reproduction are given for lakes in the Altai territory (Vesnina, 2002).

5.3. Some patterns of Artemia cyst production

5.3.1. Dependency of cyst stock on Artemia brine shrimp biomass

There was used the data obtained in years of 2000–2003 years on 14 lakes (App. 46), in Kurgan, Chelyabinsk and Omsk regions.

The correlation linear and nonparametric analyses were carried out between the indices of brine shrimp biomass (mean, maximum for season, the maximum in the first, second and third generations), the number of benthic, planktonic cysts and cysts stocks in autumn. The results of this analysis (correlation coefficients) are given in App. 47 and 48. There were 35 rows of numbers used ($n = 35$). The lakes selected for the analysis differed in morphometric characters: lakes area — from 0.5 to 83.3 km^2, the volume of "inhabited" area — from 0.3 to 33.3 million m^3.

The purpose of this analysis was to determine the parameters of the Artemia population productivity that more likely predicted cysts stocks in autumn. Therefore, the following parameters were chosen for analysis:

X_1 — average brine shrimp biomass for season (the sign ranges from 0.02 to 70.6 g/m^3);

X_2 — brine shrimp biomass for season (from 0.2 to 253.9 g/m^3);

X_3 — maximal biomass of the first generation (from 0.1 to 207.1 g/m^3);

X_4 — maximal biomass of the second generation (from 0.2 to 253.9 g/m^3);

X_5 — maximal bimass of the third generation (from 0.1 to 62.2 g/m^3);

X_6 — seasonal average number of planktonic cysts (from 6 to 560 thousand ind./m^3);

X_7 — seasonal average number of benthic cysts (from 101 to 7165 thousand ind./m^3).

The amount of cyst stocks in autumn was estimated according to the following parameters:

Y_1 — total stocks of cysts per unit volume of water (from 2.8 to 72.4 g/m^3);

Y_2 — total stocks of cysts per unit area of water surface (from 1.6 to 65.2 g/m^2);

Y_3 — stocks excluding benthic cysts (i.e. available for harvest) per unit volume of water (from 0.05 to 23.0 g/m^3);

Y_4 — stocks excluding benthic cysts (i.e. available for harvest) per unit area of water (from 0.02 to 20.7 g/m^2).

First of all, it should be noted that the average biomass was positively correlated with maximal biomass (per season and 1st and 2nd generations) (r и R_s from 0.51 to 0.80). An exception was the indicators of 3rd generation biomass which was correlated with none of the biomass under consideration.

Consequently, the capacity of the 1st and 2nd generations of brine shrimp has no significant effect on the density of the third generation which produces autumn cysts. Perhaps, in this case, the prevailing effect on the density of the 3rd generation provides the environmental conditions (salinity, temperature, oxygen content, food avaibility, etc.).

The average number of planktonic and benthic cysts for season with a linear correlation had no reliable relationship with any of Artemia brine shrimp biomass, and the number of planktonic cysts was in positive relationship with the biomass of the 3rd generation with nonparametric correlation. It is interesting that the first generation had no effect on these parameters, is likely, due to the fact that in the first generation mainly eggs and nauplii were produced.

There is a reliable linear positive correlation between the seasonal average number of planktonic and benthic cysts ($r = 0.40$).

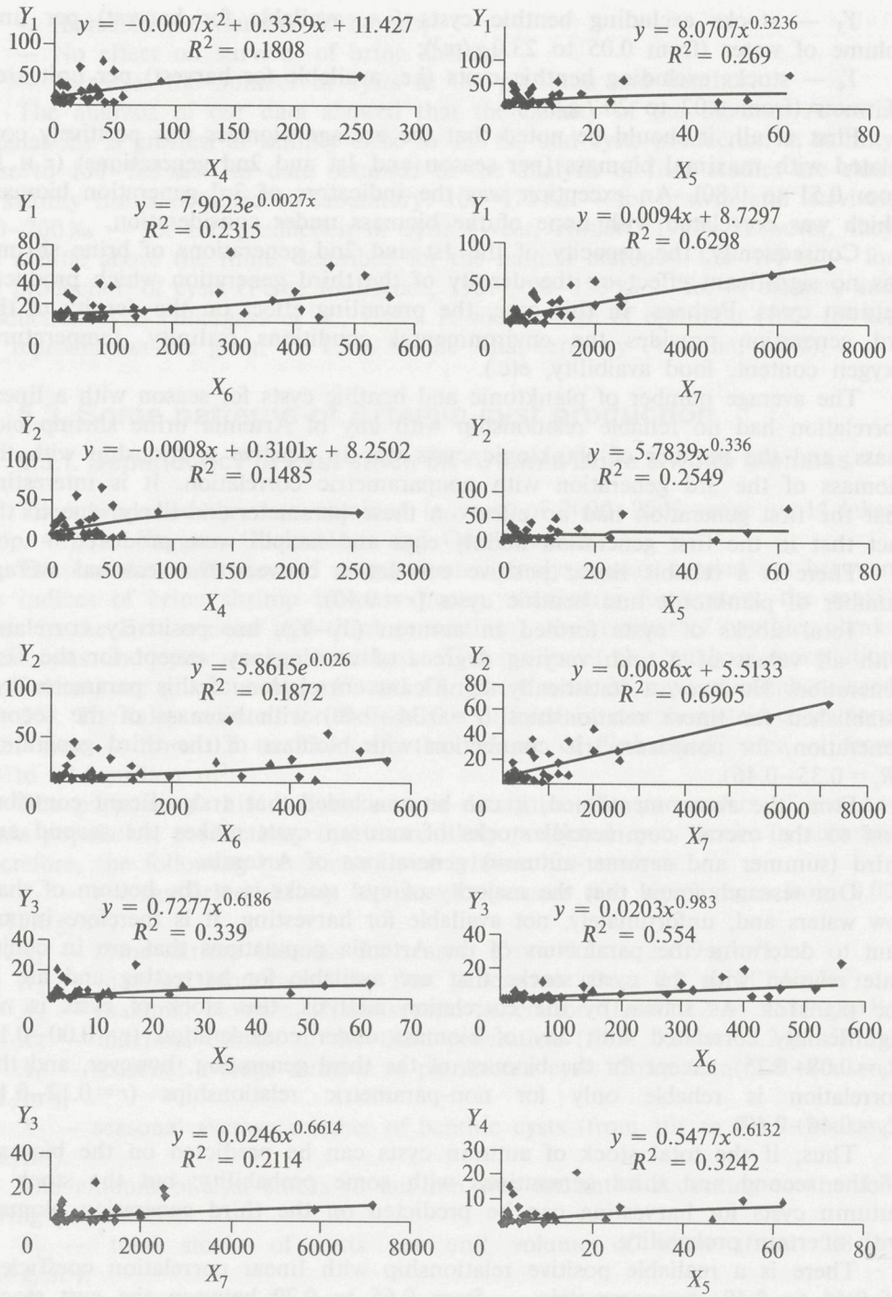
Total stocks of cysts formed in autumn (Y_1–Y_4), are positively correlated with all values of X with varying degrees of contingency, except for the first generation. However, a statistically significant correlation of this parameter was established for linear relationships ($r = 0.34$–0.40) with biomass of the second generation, for nonparametric connection with biomass of the third generation ($R_s = 0.35$–0.46).

From the above mentioned, it can be concluded that a significant contribution to the overall commercial stocks of autumn cysts makes the second and third (summer and summer-autumn) generations of Artemia.

Our research found that the majority of cyst stocks is at the bottom of shallow waters and, unfortunately, not available for harvesting. It is therefore important to determine the parameters of the Artemia populations that are in conjugate relation with the cysts stocks that are available for harvesting and are in the plankton. As shown by the correlation analysis, this stock of cysts is not significantly correlated with any of biomass under consideration ($r = 0.00$–0.10; $R_s = 0.08$–0.25), except for the biomass of the third generation, however, and this correlation is reliable only for non-parametric relationships ($r = 0.12$–0.15; $R_s = 0.46$–0.49).

Thus, if the total stock of autumn cysts can be predicted on the biomass of the second and third generations with some probability, but the stock of autumn cysts for harvesting can be predicted on the third generation biomass with acertain probability.

There is a realiable positive relationship with linear correlation coefficient of 0.44 to 0.48, nonparametric — from 0.65 to 0.70 between the cyst stocks available for harvesting (Y_3 and Y_4) and total cysts stocks (Y_1 and Y_2).



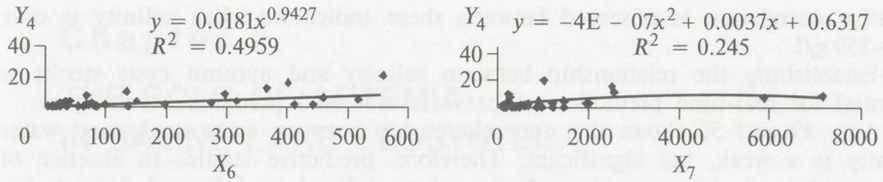


Fig. 71. Dependence of autumn cysts stocks (Y_1–Y_4) from some parameters of population density (X_4–X_7).

The equations that connect the indicators of stocks of autumn cysts and indicators of the Artemia population productivity conjugated with them (Fig. 71) were found by means of regression analyses. As shown in figures, all relationships are positive, that is, when brine shrimp biomass of the second and third generations grow, then cyst stock increase as well.

The combined influence of biomass values of the second and third generations on cysts stocks were evaluated in two ways:

— by linear regression based on the average biomass $(X_4 + X_5)/2$;

— by multiple regression.

As a result, we obtained an equation which is reliable at significance level of 5 %:

$Y_1 = 11.21 + 0.41(X_4 + X_5)/2$ $(R^2 = 0.27)$;

$Y_2 = 8.73 + 0.32(X_4 + X_5)/2$ $(R^2 = 0.22)$;

$Y_1 = 9.09 + 0.16 \cdot X_4 + 0.53 \cdot X_5$ $(R^2 = 0.36)$;

$Y_2 = 6.56 + 0.12 \cdot X_4 + 0.50 \cdot X_5$ $(R^2 = 0.34)$.

Since the stock of cysts available for fishing correlate only with biomass of the third generation, this relationship can be best described by power equation:

$Y_3 = 0.73 \cdot X_5^{0.62}$ $(R^2 = 0.34)$;

$Y_4 = 0.55 \cdot X_5^{0.61}$ $(R^2 = 0.30)$.

The obtained correlation and determination coefficients indicate the average power of relationship in which a third of variations of the total stock values depends on the variation of brine shrimp biomass of the second and third generations, and for available cysts stock for harvesting — only the third generation. Using the above formula, it is possible to judge of the expected total stock of Artemia cysts in autumn by brine shrimp biomass of the second and third generations. Since the relationship between autumn cysts stock that are available for harvesting, and the density of the second generation can not be traced, it can be concluded that the cysts laid in July — early August sink to the bottom or deposit on the shoreline.

5.3.2. Dependency of cysts stock on water salinity

Sect. 5.2 demonstrates an ambiguous effect of salinity on the number of planktonic and benthic cysts. At a salinity of 30 to 150 g/l, there is a positive relationship, i.e. when salinity increases the number of cysts grows in biocenosis, and the density peak is observed at a salinity of 150 to 180–250 g/l, and

negative correlation is observed between these indicators when salinity is over 180–250 g/l.

Establishing the relationship between salinity and autumn cysts stocks is essential for real-time prediction of harvest value and prediction techniques.

App. 49 and 50 shows that the relationship between cysts stocks and water salinity is a weak, but significant. Therefore, predictive studies in absence of data on Artemia biomass, the salinity values defined in July and August, i.e. during the vegetation season of the second and third generations can be used. The parabolic relationship between salinity and cysts stocks suggests that in lakes salinity from 100 to 220 g/l, the products of about 20 g/m^2 might be expected from all cysts, and cysts of about 5 g/m^2 available for harvesting.

Chapter 6

THE ROLE OF ARTEMIA IN SALINE LAKE ECOSYSTEM

6.1. Functioning of lake ecosystem

Shallow ultrahaline lakes in Southwest Siberia are differed by not only a high level of biological productivity, but also by organic substances and thick layer of silt accumulated on the lake bottom.

Schematically, the functioning of a typical Artemia producing lake ecosystem can be represented as follows:

— phytoplankton synthesizes organic substances, using energy from sunlight and nutrients dissolved in water;

— halophilic bacteria convert light energy into chemical energy through the purple bacteriorhodopsin protein (the prototype of chlorophyll) (Konstantinov, 1986);

— Artemia consume algae, bacteria, detritus, mineralizes organic substances nutrient and releases biogenic elements in the environment (Deksbah, 1956; Deksbah, Anferova, 1971);

— dead phytoplankton and Artemia, its feces, part of cysts turn into detritus and settle to the bottom;

— bacteria decompose detritus.

6.1.1. Primary production

One of the main sources of organic substances is the phytoplankton photosynthesis. The information on the primary production of phytoplankton in salt lakes situated on different continents (Ivanova, 1990; Novoselova, Novoselov, 2000; Carpelan, 1957; Mason, 1967; Hammer et al., 1975; Lenz, 1987), indicate that the annual primary production rarely exceeds 1000 gC/m^2. In the particular cases, the high primary production of 1000 gC/(m^2 · year) can be found in the North American Mono Lake (Mason, 1967), and 1029 gC/(m^2 · year) — in Kulundinskoye lake (Novoselova, Novoselov, 2000), 1368 gC/(m^2 · year) — in Solenoye lake in the Altai Krai (Solovov, Yasyuchenya, 2005), 2201 gC/(m^2 · year) — in one of lakes in Australia with relatively low salinity of 28–44 g/l (Ivanova, 1990).

The primary production of the five lakes was studied by the light and dark bottle or dissolved oxygen method in our investigations in years of 2000 and 2001 (see Tab. 7, Sect. 2.4.1).

The daily production rate of phytoplankton during two seasons ranged from 0.003 to 0.87 while in some stations it was up to 1.32 mgC/(l · day). It made up 0.27 mgC/(l · day) in 2000 and it was 0.13 mgC/(l · day) in 2001 in Bolshoye Medvezhiye lake, in Maloye Medvezhiye lake it was 0.50 mgC/(l · day) in 2000 and it was 0.10 mgC/(l · day) in 2001, in Vishnyakovskoye lake — 0.27 mgC/(l · day), in Nevidim lake — 0.62 mgC/(l · day) and in Ebeyty lake — 0.25 mgC/(l · day).

Consequently, daily phytoplankton production value according to the trophicity scale (Bul'on, 1983; Kitaev, 1984) allow to relate Artemia producing lakes to mesotrophic type, and in some seasons they can be related to oligotrophic type (Bolshoye and Maloye Medvezhiye in 2001).

The phytoplankton of Artemia producing lakes function all year round, even in winter there is as much phytoplankton biomass as it is in summer (see App. 11). Therefore, the seasonal average data was applied to estimate the annual production. As a result, the annual phytoplankton production was 117 gC/(m^2 · year) or 1317 kcal/(m^2 · year) on average for all lakes. On wet organic basis it was 1054 g/m^2 or about 10 tons/ha. This indicator corresponds to eutrophic type lakes according to the trophicity scale.

The phytoplankton in Artemia producing lakes is under strong pressure of filter feeder as Artemia. When Artemia dies the phytaplonkton number increases which is observed in autumn (see App. 11).

Destruction of organic substances, which reflects its rate of mineralization in Artemia producing lakes, is 180 gC/(m^2 · year), or 2029 kcal/(m^2 · year) on average. Hence, the production-to-destruction ratio was less than 1. This demonstrates that allochthonous organic substances are involved in biotic processes in lakes, and the proportion of bacteria and their production in plankton is comparable with the phytoplankton production. The negative water balance in lakes is the reflection of the fact that allochthonous organic substance is depleted in relation to carbon by biogenic elements, limiting photosynthesis (Vinberg, 1964; Bul'on, 1983).

6.1.2. Secondary production

6.1.2.1. Production of average Artemia population

It is necessary to refer to average values for determination of Artemia biomass and cysts in lakes of the entire region. In this case, methodically, it is convenient to apply the statistically average values of productivity indicators.

A. Estimates on average biomass and number of its turnings

The data taken from the literature was used for calculation of the Artemia production (Khmeleva, 1968) that 1 mg of dry matter contains 5.2 cal, and crude matter — 0.518 cal, brine shrimps body consists of 89 % of water. According to our own data: moisture of cysts is 50 %, the average weight of dry cyst is 0.005 mg, and hydrated cyst is 0.01 mg. Consequently, the caloric content of one cyst is 0.026 cal, 1 mg of dry cysts is 5.2 cal, 1 mg of crude cysts is 2.6 cal. The latter number is consistent with the conclusion made by M.B. Ivanova (1983) for crustaceans that energy equivalent of eggs is 4 times higher than the energy equivalent of crude body weight of female.

The secondary production can be estimated in several ways. The first one is quite rough and inaccurate method based on the average biomass per season and the number of generations per season. The average brine shrimp biomass for all lakes is 23.5 mg/l (see App. 31), the average of cysts is 8.39 mg/l in crude weight, summing up to 34 cal/l (see App. 32 and 33). There are 4 generations per season (see Ch. 4). As a result, the secondary production per season is 128 g/m^2 or 136 kcal/m^2 on average.

The estimation could be more accurate if the average value of biomass is multiplied by the number of its turnings per season (Zaika, 1983). Whereas, the turnover-time is equal to the average life span of population that is 46.2 days (see Sect. 4.3.2). The turnover rate (the reciprocal of the turnover-time) will be 0.022. The growing period lasts for 180 days, the biomass provides 4.0 times of "turnaround" per season. In our case this number is close to the number of generations. Therefore, the production by this method of estimation will also be equal to 128 g/m^2 or 136 kcal/m^2.

B. Estimates on the data from Matrix

This way of estimation was based on the received view the population production (P) is equal to the sum of somatic (P_s), generative (P_g), exuvical (P_{ex}) productions. Since, the matrix well describes the dynamics of the average Artemia population, this estimation and subsequent calculations were carried out according to the matrix (see Fig. 59, Sect. 4.3). The primary motivation of this estimation was based on the fact that throughout the growing season, all individuals will be eliminated at a particular age stage. The sum of all these individuals will determine the somatic production of population. The number of eliminated individuals during the season was determined as the difference between individuals of the previous and next age class. The weight of individuals eliminated was determined based on the long-term average data and is 0.02 mg for nauplii, 0.2 mg for metanauplius, 0.6 mg for juveniles, 2 mg for pre-adults, and 4 mg for adults. Simple calculations in Tab. 27 illustrates that the total number of eliminated brine shrimp biomass during the growing season was 240 mg/l or 124 kcal/m^2. 75 %

Table 27. **Biomass of eliminated shrimps in vegetative season, mg/l**

Dates of season	Nauplii	Meta-nauplius	Juvenile	Pre-adult	Adult
22.04–01.05	5.28	0.00	0.00	0.00	0.00
01.05–07.05	0.00	6.60	0.00	0.00	0.00
01.05–15.05	0.00	0.00	3.96	0.00	0.00
15.05–22.05	0.00	0.00	0.00	10.60	0.00
22.05–01.06	0.00	0.00	0.00	0.00	42.00
01.06–07.06	1.69	0.00	0.00	0.00	21.20
07.06–15.06	0.84	2.10	0.00	0.00	10.80
15.06–22.06	0.42	1.06	1.26	0.00	5.20
22.06–01.07	0.21	0.54	0.66	3.50	2.60
01.07–07.07	0.11	0.26	0.30	1.60	14.80
07.07–15.07	0.59	0.12	0.12	0.90	14.20
15.07–22.07	0.57	0.74	0.12	0.40	10.40
22.07–01.08	0.42	0.70	0.42	0.10	7.00
01.08–07.08	0.28	0.52	0.48	1.20	4.40
07.08–15.08	0.17	0.36	0.30	1.00	7.00
15.08–22.08	0.28	0.22	0.18	0.80	8.00
22.08–01.09	0.32	0.36	0.12	0.70	7.40
01.09–07.09	0.29	0.40	0.18	0.30	5.80
07.09–15.09	0.24	0.34	0.84	0.60	4.40
15.09–22.09	0.17	0.28	0.18	0.60	4.40
22.09–01.10	0.17	0.22	0.60	0.60	4.80
01.10–07.10	0.19	0.22	0.12	0.60	4.80
In total...	12.24	15.04	9.84	23.50	179.20
Sum...			239.82		

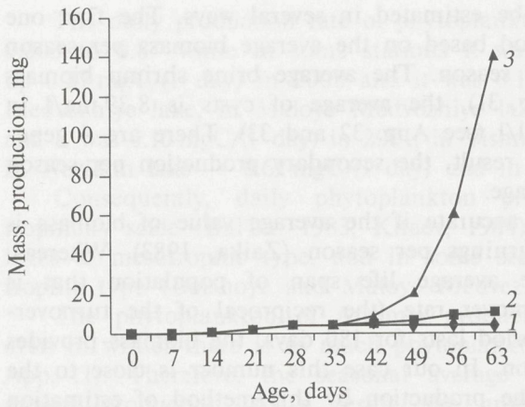


Fig. 72. Growth and production of Artemia female.
1 — individual growth curve; *2* — curve of individual products given the mass of all age stages born individuals and their mortality; *3* — the same as previous one, but without mortality.

of the eliminated biomass is accounted for the biomass of adults. Thus, the somatic production by a population over the growing season in the statistically average Artemia population was 124 kcal/m^2.

The estimation of generative production was carried out according to the number of cysts released, their weight (see Fig. 59) and energy equivalent. The total number of cysts formed was 1385 cysts/l per season. At the average weight of hydrated cysts of 0.01 mg (with moisture of around 50 %), and dry cysts of 0.005 mg, the total cyst biomass will be 13.85 mg crude weight or 6.93 mg/l dry weight. Energy equivalent will be 36 kcal/m^2.

The estimation of exuvical production (due to molts) was carried out according to the formula $P_{ex}/P_s = 0.89$ (Khmeleva, 1968; Khmeleva, Golubev, 1984). Over the growing season exuvical production of the average Artemia population was 110.4 kcal/m^2.

Thus, the total production of the Artemia populations over the growing season will be 270.4 kcal/m^2.

Relatively small generative production occurs due to the fact that some of these products entered somatic production in the form of viviparous nauplii.

The high generative production obtained in laboratory culture test (Khmeleva, 1968; Khmeleva, Golubev, 1984) is not observed in natural conditions because of the high mortality rate. For example, Fig. 72 illustrates the growth curve from nauplius stage to adult female, provided that the female has longest lifespan and laid 5 clutches during its lifetime. The figure shows that to end of life, the total production of all individuals hatched, not taking account the mortality rate, is 14 times higher than that observed in natural conditions.

Another way of the production estimation by calculation of the production rate $P'(t)$ per day was performed on the results of observations at moment in time t according to the density and weight of each age class. The production rate was calculated using the formula, originally presented in the works by G.A. Pechen' (1968) and later upgraded version by M.B. Ivanova (1985):

$$P'(t) = \sum_{i-1}^{n} (w_i - w_{i-1})N_i/D_i + w_0 N_0/D_0,$$

where w_0, w_i — weight of eggs and brine shrimp of various age classes, mg or kcal; D_0, D_i — developmental time of age class, days; N_0, N_i — number of

eggs and brine shrimp of various age class per litter; $P = P'(t) \cdot t$, where t — time interval (day, month, season).

This method assumes the knowledge of the duration of each class age.

The following data was applied for the estimation:

D_0, D_1,...$D_5 = 7$ days; $w_0 = 0.01$ mg, $w_1 = 0.02$ mg, $w_2 = 0.2$ mg, $w_3 = 0.6$ mg, $w_4 = 2.0$ mg, $w_5 = 4.0$ mg. Brood size of 20 eggs. This data was obtained from the literature (Khmeleva, 1968; Khmeleva, Golubev, 1984; Schrehardt, 1987; Criel, 1991; Golubev, 2004), and from our own observations (Litvinenko et al., 2002). In calculations it was assumed that the female do not increase in their weight after reaching adult stage.

The estimation of production is presented in App. 51. The graph built according to the data in this table (Fig. 73), has a sinusoidal character of the curve with oscillations gradually decaying. The maximum production occurs in the period of growth of juveniles and pre-adults. With this method of estimation, the total production over the growing season will be 288 kcal/m^2. Thus, the similar results were obtained by the second and third methods.

The following method of calculation was carried out on the basis of physiological method according to the known balance equation (Vinberg, 1968): production = assimilation — metabolic expenditure.

The calculation of the Artemia production was carried out by the balance equation of N.P. Makarova (1972) with a coefficient of food assimilation (U) 0.8 and $t = 25$ °C, taking into account a dry weight of 20 % from crude weight:

$$dP/dt = 0.0239w^{0.705} - 0.0118w^{0.688},$$

where P and w — production and weight of brine shrimp in grams of dry weight.

According to this formula, the daily nauplii production (wet weight of 0.02 mg, dry weigh of 0.004 mg), metanauplius (wet weight of 0.2 mg, dry of 0.04 mg), juveniles (wet weight of 0.6 mg, dry of 0.12 mg) pre-adults (wet weight of 2.0 mg, dry of 0.4 mg), adults (wet weight of 4.0 mg, dry of 0.8 mg) will be equal to 0.000223, 0.001182; 0.002617; 0.006245; 0.01030 mg of dry biomass,

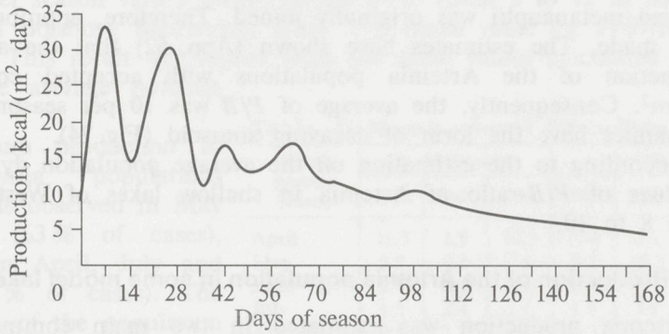


Fig. 73. Change in daily rate of production of Artemia populations during the growing season according to the matrix.

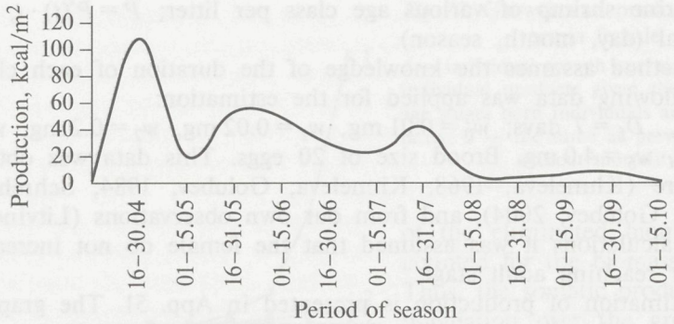


Fig. 74. Dynamics of Artemia production according to average statistical population.

respectively. Using the density data of average population model (see Fig. 59), the seasonal population production of 14.5 mg/l dry weight, which corresponds to 75.7 kcal/m^2 was obtained.

As can be seen, the resulting production is approximately 4 times lower than the production, calculated by the above listed methods, and 1.6 times lower then somatic production which was calculated based on the eliminated biomass.

Probably, estimation methods of eliminated biomass and productin rate are still more correct. Therefore, in further calculations, the physiological method, which, strictly speaking, accounts only somatic production rate, was excluded from the production calculation.

Seasonal *P/B*-ratio, defined as the ratio of production per season divided by mean biomass for the average population calculated based on the eliminated biomass and growth rate, is equal to 7.9 and 8.7 respectively. Because of the big difference in caloricity of crude brine shrimp and eggs, we consider that it more correct to use the energy equivalent of mean biomass and production in determining *P/B*-ratio.

According to Tab. 22 (see Ch. 4), the seasonal production calculated for all lakes was calculated by the formula of G.A. Pechen' (1968), where the number of nauplii and metanauplii was originally joined. Therefore, appropriate adjustments were made. The estimates have shown (App. 52) that the average seasonal production of the Artemia populations with accepted conditions is 340.11 kcal/m^2. Consequently, the average of *P/B* was 10 per season. The production dynamics have the form of decaying sinusoid (Fig. 74).

Thus, according to the estimation on the average population dynamics, the seasonal values of *P/B*-ratio of Artemia in shallow lakes of Western Siberia ranges from 8 to 10.

6.1.2.2. Production of the Artemia population in some model lakes

The Artemia production was estimated in two main commercial lakes Bolshoye Medvezhye and Nevidim during three seasons (2001–2003). The first lake relates to highly saline lake with relatively more stable hydrochemical re-

Table 28. **Average seasonal values of production, biomass of shrimps and cysts in modeling lakes for the three-year period**

Year, parameter	B. Medvezhye				Nevidim			
	Products for season	Mean seasonal biomass		*P/B*	Products for season	Mean seasonal biomass		*P/B*
		shrimps	cysts			shrimps	cysts	
	kcal/m^2				kcal/m^2			
2001	364	9.7	12.6	16.3	596	31.5	20.1	11.5
2002	451	16.5	22.4	11.6	132	4.5	12.7	7.7
2003	130	5.2	8.1	9.8	133	4.9	6.8	11.4
M	315	10.5	14.4	12.6	287	13.6	13.2	10.2
σ	166	5.7	7.3	3.4	267	15.5	6.7	2.2
C_v, %	53	54	51	27	93	114	51	21

gime in the seasonal and interannual aspect, the second lake becomes freshwater lake in wet years and switches to the first class of salinity characterized by depression of Artemia because of food competition (see Sect. 3.4.2), which was observed in 2002 and 2003.

In general, over three years of scientific investigation, the seasonal production of Artemia in these lakes ranged from 130 to 596 kcal/m^2 (97–1008 g/m^2) (App. 53). The average three-year production was 315 kcal/m^2 (305 g/m^2) in lake Bolshoye Medvezhye and it was 287 kcal/m^2 (491 g/m^2) per season in lake Nevidim. On wet shrimps and cysts basis it was 3 t/ha and 5 t/ha respectively.

The production values obtained on the lakes studied commensurated with the production of Artemia in relatively deep-water Great Salt Lake (Utah, USA) located to the south (latitude 41°00' N) from the lakes studied. The annual Artemia production estimation ranges from 100 to 200 g/m^2 of dry weight (Lenz, 1987) or in wet weight of 300–700 g/m^2.

In the lakes being analyzed, the production and brine shrimp biomass were more inconsistent in lake Nevidim (C_v from 93 to 114 %). The indicators for Bolshoye Medvezhye lake were relatively more stable (C_v from 51 to 54 %). The *P/B*-ratio (Tab. 28) were the least variable (C_v 21 and 27 %): values for *P/B*-ratio per season varied within ranges 8–16 (from 8 to 12 in lake Nevidim, 10 to 16 in Bolshoye Medvezhye lake). The mean value for *P/B*-ratio is equal 11.4 ± 1.16. This result was higher than the same values calculated by the matrix for the average Artemia population.

Maximum production in the Artemia populations (Fig. 75) was observed in May and June (63 % of cases), rarely — in April, July and August (12 % of cases). The growth rate of the population density is the highest in April and May. In all cases, the

Table 29. **Monthly values of *P/B*-coefficient**

Month growing season	B. Medvezhye			Nevidim			*M*
	2001	2002	2003	2001	2002	2003	
April	11.3	1.9	10.1	17.4	2.1	0.0	7.1
May	5.5	9.6	7.4	9.3	15.8	15.2	10.5
June	1.4	4.4	2.1	2.3	9.5	3.4	3.9
July	1.3	2.4	1.7	1.3	3.1	0.5	1.7
August	0.2	1.2	0.4	0.3	0.1	0.0	0.4
September	0.1	0.6	0.4	0.2	0.1	0.1	0.2
October	0.2	0.0	0.0	0.0	0.1	0.0	0.1

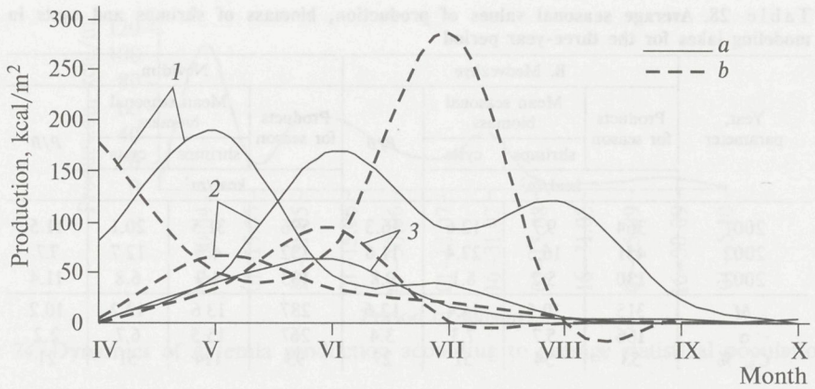


Fig. 75. Dynamics of production of Artemia population in modeling lakes for the three-year period (2001–2003).

Lakes: *a* — Bolshoye Medvezhye, *b* — Nevidim; year: *1* — 2001, *2* — 2002, *3* — 2003.

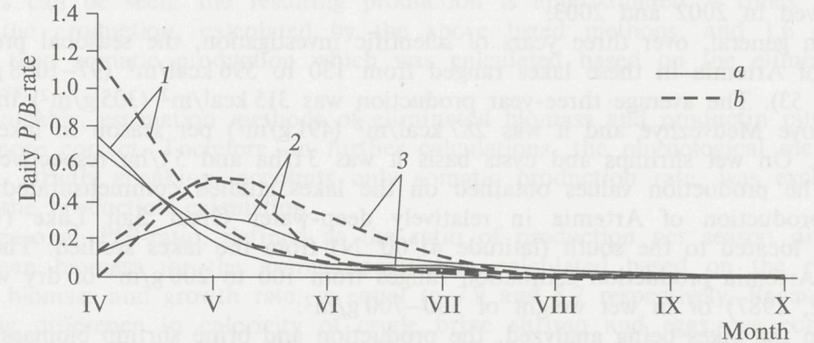


Fig. 76. Seasonal dynamics of daily *P/B*-coefficient in modeling lakes for the three-year period (2001–2003).

Lakes: *a* — Bolshoye Medvezhye, *b* — Nevidim; year: *1* — 2001, *2* — 2002, *3* — 2003.

increase in production rate was accompanied by an increase in growth rate of population density. The mean values for daily *P/B*-ratio are 0.47 in April, it is 0.35 in May, it is 0.13 in June, 0.06 — in July, in August — 0.012, in September — 0.008, in October — 0.004 per day (Fig. 76). This dynamic is especially well expressed for monthly *P/B*-ratio (Tab. 29). The comparison shows that the maximum rate of population density growth is observed in the period of the prevalence of fast-growing community of young stages from April to June.

Thus, in April when the community consists of nauplii exclusivly, the density growth rate is the highest. Since July, when the community is dominated by the adults, the growth rate is reduced to 0.06 day^{-1}, and the subsequent decrease in growth rate from August to October, probably, due to the influence of temperature on this indiciator.

6.1.2.3. *P/B*-ratio

The value of the seasonal *P/B*-ratio of 3 was applied for prediction of the Siberian Atemia population (Solovov, Podurovsky, Yasyuchenya, 2001). Our results showed that the value of *P/B*-ratio was underestimated and obtained by rough estimation.

In our studies, the value for the *P/B*-ratio obtained by different ways of estimation is in the range from 8 to 11 and in an average of nearly 10 per season.

It should be noted that the value for the *P/B*-ratio were not taken into account (estimation method is given in Ch. 7) in definition of total allowable catch (TAC) of Artemia cysts. The value for the *P/B*-ratio were to determine the TAC of Artemia shrimp biomass. As the somatic production is used in Artemia biomass harvesting it is important to know the value for the *P/B*-ratio for somatic production in units of wet weight (the ratio of somatic production to an average brine shrimp biomass). The values of seasonal *P/B*-ratio from 10.2 to 37.0 with an average of 22.3 ± 2.6 (daily — 0.12) can be obtained by using the data from all available estimations.

The daily values of the growth rate of Artemia weight depending on the age given below according to the V.E. Zaika (1983) at temperature of 25 °C, corresponds to the investigated middle-aged populations:

Age, day	5	10	**15**	20	25;
C_w, day^{-1}	0.49	0.21	**0.12**	0.07	0.05.

However, as a recommended precaution in prediction (Babayan, 2000), we consider that at the moment (the Artemia biomass harvest technology is not perfected yet) it is more acceptable to use the minimally obtained value for seasonal *P/B*-ratio of 10, and of daily value of 0.056 in definition of the total allowable catches (TAC) of Artemia biomass.

Similar values for *P/B*-ratio were obtained for the Artemia populations in lakes of Kazakhstan: seasonal — from 11.25 to 17.39, daily — from 0.03 to 0.22 (Matmuratov et al., 2004).

In addition, it should be noted that the daily values for *P/B*-ratio were closer to the values estimated for copepods, than for cladocerans: so, M.B. Ivanova (1983) gives the average values of 0.07 ± 0.01 for *Copepoda*, and value of 0.16 ± 0.04 for *Cladocera*. This once again confirms the low competitiveness of Artemia in comparison with the cladocerans as *Moina*. Artemia can thrive only under conditions of high salinity and in the absence of competitors.

6.1.3. Transformation of energy and trophic level ratio

Trophic structure of biocenosis of Artemia lake is represented by producers, primary consumers and decomposers. For an average community, Artemia production makes up from 20 to 26 % of phytoplankton production according to various estimates, which is slightly higher value than the one corresponding to the general provision of Ecology: $P_{n+1}/P_n \approx 0.1$ (Odum, 1975) and is within the oscillations (0.16–0.34), established for the various lakes (from clean lake to contaminated Bay) (Ivanova, 1985).

Table 30. **Ratio of organism's production in adjacent trophic levels**

Lake	Year	P_2	P_1	P_2/P_1
B. Medvezhye	2001	364	873	0.42
	2002	451	746	0.60
	2003	130	242	0.54
Nevidim	2001	596	1433	0.42
	2002	132	2346	0.06
	2003	133	363	0.37
M		301	1001	0.40

Note. P_1 — production of phytoplankton; P_2 — production of Artemia population, kcal/m^2.

When considering different populations investigated (Tab. 30) it was revealed that the ratio P_2/P_1 is very different (0.06–0.60). Phytoplankton coming out of the press of filter feeders obtains higher development in biocenosis with low Artemia density.

Perhaps, a higher ratio of two adjacent trophic levels is due to the fact that there are halophilic bacteria, detritus and benthic microflora besides to phytoplankton in Artemia diet.

It is well known (Ivanova, 1985) that the P_2/P_1-ratio practically independent of the trophic status of lakes, but sudden changes can be expected when a lake is very contaminated, and P_2/P_1-ratio increases with a significant inflow of allochthonous organic.

6.2. Role of Artemia in water purification

In hypersaline lakes, Artemia brine shrimp is a major consumer of suspended organic substance consisting of algae, bacteria and detritus.

The rate of water filtration in relation to brine shrimp diet to food concentration in water was estimated to clarify the role of Artemia in lake self-purification.

6.2.1. Daily food rations

Since the diet of Artemia is a parabolic function of mass, there was used the formula of consumed diet dependency (*C*, gram of wet weight of food per individual) from weight (*W*, gram of wet weight of brine shrimp body) for the calculation of brine shrimp rations of various age classes (Suschenya, Khmeleva, 1967):

$$C = 0.063\ W^{0.705}\ \text{g} \cdot \text{days}^{-1}.$$

The caloricity value of 0.6 cal/mg of wet weight was used for transformation to energy equivalent.

App. 54 shows the estimation of average brine shrimp ration per season for all age classes in the two model lakes over three years of research. The total daily ration for all brine shrimp daily ration was in the range of 2.0 to 11.2 cal/(l · day). The average daily production of Artemia in same lakes was in the range of 0.55 to 2.79 cal/(l · day). The ratio of products to the consumed diet (*P/C*) in our studies ranged from 0.19 to 0.45 with an average of 0.29 ± 0.04, $C_v = 34\ \%$. This ratio, which is called the growth coefficient of the first order (K_1) (Ivlev, 1939), is an important factor of the biocenose productivity, as it shows the degree of assimilated food utilization on growth, i.e. the ratio of energy output in the form of Artemia production to the amount of energy in consumed food. In other words, the findings suggest that almost 30 % of the

Table 31. **Daily average values of diet, production and metabolism of Artemia populations**

Lake, year	*C*	*P*	*T*	*C/T*	*T/P*	$K_2 = P/(T+P)$	$K_1 = P/C$	$q = (T+P)/C$
B. Medvezhye								
2001	4.44	2	1.18	3.76	0.59	0.629	0.450	0.72
2002	8.60	2.2	2.22	3.87	1.01	0.498	0.256	0.51
2003	2.88	0.55	0.74	3.89	1.35	0.426	0.191	0.45
Nevidim								
2001	11.15	2.79	2.92	3.82	1.05	0.489	0.250	0.51
2002	1.95	0.72	0.52	3.75	0.72	0.581	0.369	0.64
2003	2.66	0.59	0.69	3.86	1.17	0.461	0.222	0.48
M	5.28	1.48	1.38	3.83	0.98	0.51	0.29	0.55
σ	3.74	0.97	0.97	0.06	0.28	0.08	0.10	0.10
C_v, %	71	66	71	2	29	15	34	19
m	1.53	0.40	0.40	0.02	0.11	0.03	0.04	0.04

Note. *C, P, T* — daily average values for consumed diet of Artemia population, production and metabolic expenditure, respectively, cal/l; *q* — degree of assimilation of the consumed food.

consumed food by Artemia used for growth. Ecological efficiency of the natural Artemia populations was higher than the values of K_1 (0.18) obtained in laboratory by N.N. Khmeleva (1968). The calculated values are close to the maximum values, marked for invertebrates in the range of 0.30–0.40 (Konstantinov, 1986). Perhaps, the relatively high values of K_1 in natural conditions occur because of lower food supply when the best food assimilability is observed. It is known that at higher concentrations of food in nature, the amount of daily diet of Artemia can be increased up to 160 % of body weight (Suschenya, 1964), while food assimilation rate is significantly decreased. Such relatively high indicators of production efficiency of Artemia is explained by the well-known (Alimov, 1989) inverse dependence of production efficiency of the community from their diversity. As it has been shown, in a typical Artemia lakes (but as a model were chosen such lakes) Artemia develop in "monoculture".

Food assimilation rate of Artemia being determined (Tab. 31) (on average 0.55 ± 0.04), corresponds to these indicators for various filter feeders (Kryuchkova, 1984; Khmeleva, Golubev, 1984). Such assimilability is marked for Artemia when feed on algae *Dunaliella* (Gibor, 1957) and yeast cells (Suschenya, 1962).

6.2.2. The rate of water filtration

Phytoplankton and detritus were found in the diet of brine shrimp, wherein the proportion of phytoplankton ranged from 5 to 50 % with an average of 17 %, $C_v = 94\ \%$. To meet their daily food requirements, brine shrimp should consume 0.17–1.67 cal/(l · day) of phytoplankton or 0.22–2.09 mg/(l · day), with phytoplankton caloricity value of 0.8 cal/mg and 0.98–9.48 cal/(l · day) or 1.95–18.96 mg/(l · day) of detritus with caloricity value of 0.5 cal/mg.

Since the amount of seston is difficult to estimate (calculation by permanganate oxidation gives greater error), the filtration rate of food was estimated by content of phytoplankton in water and in the daily diet of brine shrimp, given the fact that Artemia is nonselective filter feeder. To consume phytoplankton of 0.22–2.09 mg/l per day when its content in water column is in an

Table 32. **Calculation of volume of filtration Artemia shrimps water**

Parameter	B. Medvezhye			Nevidim			M	σ	C_v, %
	2001	2002	2003	2001	2002	2003			
The average biomass of shrimps, mg/l	14.6	24.7	6.3	42.8	3.7	6.5	16.43	13.73	84
The average daily diet Artemia population (C), cal/l	4.44	8.60	2.88	11.15	1.95	2.66	5.28	3.41	65
Mean seasonal biomass phytoplankton, mg/l	0.50	0.27	0.12	1.32	2.16	0.16	0.76	0.75	99
The proportion of phytoplankton in the diet:									
%	15	5	6	15	50	8	17	15.50	94
cal	0.67	0.43	0.17	1.67	0.98	0.21	0.69	0.52	75
mg	0.83	0.54	0.22	2.09	1.22	0.27	0.86	0.65	75
The volume of water filtered population, l	1.67	1.99	1.80	1.58	0.56	1.66	1.54	0.46	30
Filtration volume per mg of weight, ml/mg	114	81	286	37	152	256	154	90	58

amount of 0.12–2.16 mg/l there must be filtered from 560 to 1990 ml of water. In brine shrimp biomass terms, a daily specific filtration rate in the amount from 37 to 286 ml/mg of raw brine shrimp biomass can be obtained. The resulting average values (Tab. 32) of filtration rate (154 ± 37 ml/(mg · day), $C_v = 58$ %) is attributal to brine shrimp that inhabit in mesotrophic water bodies (Gutelmaher, 1983). Similar values of daily filtration rate are observed for the lakes of the Altai territory: 110–316 ml/(mg · day) (Novoselova et al., 1996).

Thus, brine shrimp filtered from 60 to 200 % per day with an average of 154 % of the volume of water mass or the entire water volume of lake is filtered within 12–40 hours.

The similar results were obtained earlier (in 2000) for Bolshoye Medvezhiye (Medvezhye lake..., 2001). The weaker filtration rate is specified for the lakes of the Altai territory: Kulundinskoye, Kuchukskoye and Bolshoye Yarovoye (Novoselova et al., 1996; Studenikina, 1999). The Artemia populations in these lakes completely filter the entire volume of water only, respectively, 3.8, and 4.7–5.9 and 1.5–6.4 days, which can be explained by a lower brine shrimp biomass in these lakes.

Extremely high filtration capacity of Artemia, shown in our study, explains the high transparency of water in Artemia producing lakes.

6.3. Energy balance

The energy balance of the Artemia populations was estimated to assess the role of Artemia in biotic balance of salt lakes. For this, in addition to data on production (P) and the daily consumed diet (C) it is necessary to know the amount of energy use of Artemia for respiration (R). The energy use for respiration was determined by the equation of N.N. Khemeleva (1968):

$$R = 0.344 \cdot W^{0.688},$$

where R — respiration rate at $t = 20$ °C, ml O_2/(hour · ind.), W — dry weight, gram.

There was used the oxy-caloric coefficient of 4.86 cal/ml O_2 for transition into units of energy.

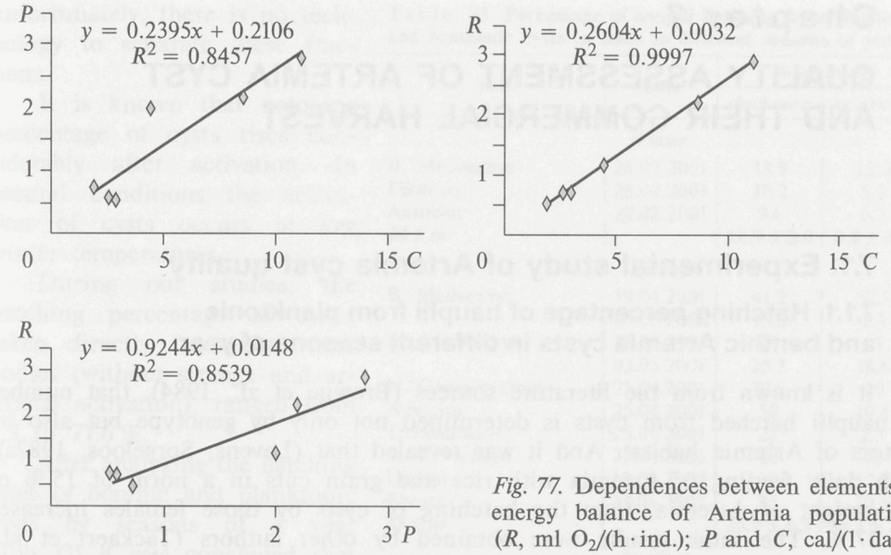


Fig. 77. Dependences between elements of energy balance of Artemia populations (R, ml O_2/(h · ind.); P and C, cal/(l · day)).

According to this formula, the daily energy expenditure for respiration from nauplius stage to mature range from 0.005 to 0.20 cal/ind. (see App. 54). With regard to the specific populations of the three model lakes within 3 years of scientific research, the average seasonal factor was in the range of 0.52 to 2.92 cal/(l · day). There is close relationship between the individual elements of the energy balance: the correlation coefficient with the pair-wise comparison of production, diet and energy use for respiration is not less than 0.92 (Fig. 77). Low variability in various populations has the indicator of C/R with an average of 3.83 ± 0.02, $C_v = 2$ %, above the average variability has the indicator of R/P (0.98 ± 0.11, $C_v = 29$ %). Thus, based on this data, it can be said that the consumed diet is almost 4 times higher than the metabolic expenditures for respiratory.

An important indicator of the productivity of biocenosis is the coefficient of used assimilated energy on growth: $K_2 = P/(P + R)$. In the studied model lakes during the three seasons K_2 was in the range from 0.43 to 0.63 with an average of 0.51 ± 0.03, $C_v = 15$ %. Lower values of K_2 (0.36) obtained in studies by N.N. Khmeleva (1968), possibly, were due to the fact that the Artemia cultivating of Artemia was carried out at a higher temperature of 25 °C than in the population under our study at a temperature of 21–24 °C. It is known (Konstantinov, 1986) that a value of K_2 of Artemia decreases sharply when temperature rises. So, the coefficient of K_2 of Artemia is quite high both from natural populations and in culture conditions, given that K_2 is equal to 0.24 on average with a fluctuations from 0.14 to 0.38 for the plankton community (Ivanova, 1985). Although, there is data in the literature on higher values of this indicator — up to 0.4–0.6 for a variety of aquatic hydrocoles (Methods of determination of products..., 1968).

Chapter 7

QUALITY ASSESSMENT OF ARTEMIA CYST AND THEIR COMMERCIAL HARVEST

7.1. Experimental study of Artemia cyst quality

7.1.1. Hatching percentage of nauplii from planktonic and benthic Artemia cysts in different seasons of year

It is known from the literature sources (Browne et al., 1984), that number of nauplii hatched from cysts is determined not only by genotype but also by factors of Artemia habitat. And it was revealed that (Lavens, Sorgeloos, 1987a), with daily feeding of Artemia with rice and grain cuts in a norm of 15 % of wet weight of Artemia, then the hatching of cysts by those females increases by 27 %. The same results were obtained by other authors (Tackaert et al., 1987) when used live algae as food. According to the literature data (Versichele, Sorgeloos, 1980; Lavens, Sorgeloos, 1987a), a tempereature weakly influences the hatching percentage (tested at temperatures of 20 and 28 °C), but there is strong influence of salinity (tested at salinities of 35, 90 and 180 ‰), and the highest hatchability was observed in the cultivation of Artemia shrimps at salinity of 90 ‰. The harvest technology greatly influences on the quantity of cysts hatched. The cysts harvested from the water surface are of the highest quality (Lavens, Sorgeloos, 1987a).

The factor that stimulates females to produce diapaused egg is temperature factor and high salinity. In our region, the massive mortality of Artemia and cyst producing occur in the second half of August and continues until mid-September.

Some proportion of Artemia cysts, even if they are placed in optimal conditions for embryonic development, remain in a state of diapause or reversibly interrupted metabolism. Probably, this mechanism was formed as a defensive response for existence of the population in dramatically changing living conditions.

As a rule, harvested and stored cysts contain two factions: the cysts that are in the state of diapause (dormancy) and cysts that are in a state of quietness, but already activated (quiescence). The diapaused cysts first must be activated in order to hatch, while activated cysts require suitable conditions for incubation. Our studies have shown that these fractions are well distinguished by chorion color. After a 30 hour incubation, hatching of nauplii from light-colored cysts was equal to 96.6 % ($\sigma = 1.0$) on average, and from dark-colored cysts was 5.1 % ($\sigma = 0.7$). The presence or absence of dark oily spots on cysts almost did not change the hatching percentage. Thus, the cysts with the darkest color of chorion, with a very high probability, are diapausing cysts. However,

unfortunately, there is no technology to separate these fractions.

It is known that hatching percentage of cysts rises considerably after activation. In natural conditions the activation of cysts occurs at low winter temperatures.

During our studies, the hatching percentage of cysts, taken directly from the water bodies (without storage and artificial activation), ranged from 1.3 to 77.6 %.

After analyzing the hatching rates of benthic and planktonic cysts by seasons of a year (Tab. 33) it was concluded that the lowest hatching percentage was observed in winter. There is a sharp increase of this indicator for planktonic and benthic cysts in spring. Hatching of cysts which were formed in summer, is at a lower level than of autumn cysts, and the greater than spring cysts. The hatching rate of planktonic cyst in spring is significantly higher than those in summer and autumn. There were no significant differences found for benthic cysts. This indicator is the most important for the population in spring when the number of the first generation brine shrimp is formed. As the Table shows, the hatching percentage of planktonic cysts in different lakes ranges from 17 to 77.6 with an average of 35.9 %, and of benthic cysts is from 1.3 to 57.5 with an average of 19.1 %.

Table 33. **Percentage of nauplii hatching from planktonic and benthonic cysts in lakes in different seasons of year**

Lake	Date	% hatching	
		planktonic	benthonic
	Winter		
B. Medvezhye	26.02.2001	18.9	12.5
Filatovo	28.02.2001	10.2	5.3
Aktoban	28.02.2001	9.6	6.2
M* ± *m		**12.9 ± 3.0**	**8.0 ± 4.6**
	Spring		
B. Medvezhye	19.04.2001	41.2	57.5
	03.05.2001	35.6	1.3
M. Medvezhye	26.04.2001	20	13
	03.05.2001	25.3	18.6
N.-Georgievskoye	21.04.2001	77.6	5.9
Nevidim	25.04.2001	50	10.8
Trebushinoye	25.04.2001	27	2.3
B. Kureynoye	25.04.2001	40	40
Ulzhay	18.05.2002	17	30.8
Ebeyty	18.05.2002	25	10.5
M* ± *m		**35.9 ± 5.7**	**19.1 ± 2.5**
	Summer		
Ebeyty	23.06.2001	7.2	5.1
	12.07.2001	8.5	6.3
	04.07.2002	21	7
N.-Georgievskoye	04.07.2002	7.1	5.5
M. Medvezhye	04.07.2002	19.9	18.2
Filatovo	04.07.2002	30	23.1
Vishnyakovskoye	04.07.2002	18.6	16.2
Ulzhay	04.07.2002	16.2	15.3
M* ± *m		**15.6 ± 2.9**	**10.9 ± 2.5**
	Autumn		
Nevidim	19.10.1996	16.7	16.9
	24.10.2001	29.3	26
	16.11.2001	27.8	23
Filatovo	18.10.1996	17.1	15.2
	15.11.2001	18.4	17.2
Solenoye 18 (Okunevo)	30.11.1998	45.5	39.3
Ulzhay	22.11.1999	10.5	12
	16.11.2000	4.5	5.3
Ebeyty	10.10.2001	3.1	2.2
	09.11.2002	27	19
	26.11.2002	27.2	26.3
M. Medvezhye	25.10.2001	21.4	19.3
	18.11.2001	11	8.9
B. Medvezhye	25.10.2001	14.7	13.2
	17.11.2001	22.4	23.6
Vishnyakovskoye	22.10.2001	4.6	2.3
B. Kureynoye	14.11.2001	29	31.3
Gashkovo	13.11.2001	35.8	37.9
Trebushinoye	15.11.2001	24.9	26.1
Aktoban	14.11.2001	32.8	33.8
Umreshevo	16.11.2001	5.3	4.9
N.-Georgievskoye	18.11.2001	15.4	15.9
M* ± *m		**19.6 ± 2.4**	**18.9 ± 2.3**

7.1.2. Determination of optimal incubation conditions for cysts of the Siberian Artemia populations

7.1.2.1. Determination optimum of salinity

Seawater with salinity of 35 ‰ is used for practical convenience for incubation at aquaculture facilities. In the absence of natural sea water, a solution is prepared, consisting of two basic salts: NaCl and $NaHCO_3$, i.e. of the food non-iodized salt and soda. To improve the buffering capacity of solution and maintain optimum pH level of the medium 2 g/l of soda is applied in all cases. There are some disputes in terms of NaCl concentration. Some researchers (Bogatova, 1980; Voronov, 1986; Gusev, 1991) recommend using the solution with salinity level similar to that of seawater, i.e. NaCl at a concentration of 30–35 g/l. In other publications (Sorgeloos et al., 1986) it was recommended a lower NaCl concentration of 5 g/l. According to research (Clegg, 1964) the salinity of the medium has an impact on internal osmotic pressure in developing cysts.

It is known (Dutrieu, 1960; Clegg, 1964; Sorgeloos et al., 1986) that Artemia cysts contain large amounts of carbohydrates in the form of trehalose (17 % of the weight). The trehalose content drops to almost zero by the time of nauplius release. The process of aerobic metabolism assures the conversion of bulk of trehalose into an energy source i.e. glycogen and glycerol, which is accumulated inside the outer cuticular membrane of the cyst. When salinity rises, the oxidation process of trehalose slows down much as well as glycogen synthesis, followed by sharp increase in glycerol synthesis. Increased level of the latter hygroscopic component result in further water uptake by the embryo through the outer embryo cuticular membrane. The osmotic pressure inside the outer cuticular membrane builds up continuously to the point that a critical level is reached which induces the breaking of the cyst envelope. In other words the metabolism in Artemia cysts prior to the breaking is a trehalose-glycerol hyperosmotic regulatory system. This means that as salinity levels in the incubation medium increase, higher concentrations of glycerol is built up which will result in the burst of the shell and hatching, and less energy reserves will thus be left in the nauplius.

Consequently, it is necessary to find the minimum salinity level in the incubation medium in which the hatching percentage of the local populations would be maximal. For this, several experiments were conducted with freshly collected unactivated cysts. In all the experiments, a soda solution having a concentration of 2 g/l was introduced into the incubation solution. The counts were performed in 10 replicates to estimate the reliability of results.

The effect of NaCl in concentrations of 0 (distilled water), 1, 5, 10, 20, 35 g/l was studied in the first experiment.

The effect of NaCl at three concentrations of 5, 15 and 30 g/l was studied in the second experiment.

The effect NaCl at two concentrations of 5 and 30 g/l was studied in a third experiment.

The experimental results are presented in Tab. 34.

Table 34. **Percentage of nauplii hatching at different salinity**

Number of experience	Place of sampling cysts	Concentration NaCl, g/l	t, °C	$M \pm m$, %	C_v, %	The differences are not significant at concentrations of NaCl, g/l
1	B. Medvezhye	0	25	6.8 ± 1.2	42	1
		1	25	8.9 ± 1.4	39	0
		5	25	33.4 ± 1.9	14	10, 20, 35
		10	25	31.5 ± 0.8	7	5, 20, 35
		20	25	37.8 ± 1.0	7	5, 10, 35
		35	25	40.1 ± 2.4	14	5, 10, 20
2	B. Medvezhye	5	22	40.0 ± 1.2	7	
		15	22	36.4 ± 1.2	8	
		30	22	23.8 ± 0.9	10	
		5	25	36.7 ± 0.8	6	15
		15	25	37.7 ± 0.9	6	5
		30	25	33.0 ± 1.0	7	
3	B. Medvezhye	5	25	32.0 ± 5.4	41	30
		30	25	31.5 ± 0.4	3	5
	Nevidim	5	25	77.8 ± 1.2	4	30
		30	25	72.9 ± 0.6	2	5
		5	22	76.9 ± 0.8	3	
		30	22	68.1 ± 0.6	2	
	B. Yarovoye	5	25	58.9 ± 0.9	4	
		30	25	52.2 ± 1.0	5	

The analysis of the data of the first experiment showed that release of nauplii is possible even in distilled water (with addition of soda 2 g/l), however, the hatching percentage in these conditions is the lowest of 6.8 %. Low hatching was also observed when the concentration of NaCl was 1 g/l. The differences in the hatching percentage in these two salinities were not reliable. The increase in concentrations of NaCl up to 5 g/l results in an increase in the hatching percentage by 3.8–4.9 times as compared with the first two concentrations. The successive increase in medium salinity usually leads to a gradual increase in hatching percentage. Wherein, the differences between the concentrations of NaCl from 5 to 35 g/l in this indicator were unreliable. The highest hatching percentage was recorded at a salinity of 35 g/l (40.1 %).

In the second experiment, when the effect of three different concentrations of NaCl was tested, the experiments were carried out at two temperatures of 22 and 25 °C. The hatching percentage decreased significantly from 40.0 to 23.8 % at temperature of 22 °C when concentrations of NaCl were increased from at 5 to 30 g/l. At a temperature of 25 °C these changes were not significant: from 36.7 % (at 5 g/l) to 33.0 % (at 30 g/l).

In the third experiment, when the effect of two concentrations of NaCl was tested, the experiments were conducted with three various populations of Artemia cysts at the same temperature of 25 °C, and also with cyst from the same population but at two temperatures of 22 and 25 °C. In the first variant of the experiment with different populations it was found that nauplii from cysts of Medvezhye lake almost equally hatched ar both concentrations of

NaCl, but this indicator was higher at low concentration for Nevidim lake cysts, however, these differences were unreliable. The nauplii from cyst of Bolsgoye Yarovoye lake hatched significantly better at a NaCl concentration of 5 g/l. In the second variant of the experiment with the cysts from Nevidim lake, this indicator was higher at both temperatures at a NaCl concentration of 5 g/l, but the differences were only reliable at a temperature of 22 °C.

Thus, it can be concluded that in the absence of natural sea water to the incubation of Artemia cysts in order to save the best use salt solution: 5 g/l NaCl and 2 g/l $NaHCO_3$, since an increase in concentration of NaCl in the solution does not significantly improve the nauplii hatching percentage and in some cases even reduced.

7.1.2.2. Determining optimal incubation temperature

In nature hatching nauplii from cysts begins when water temperature warmed up to 4–5 °C. Most of the scientific researchers recommend to maintain the temperature of 25–30 °C (Sorgeloos et al., 1986; Voronov, 1986) reasoning that cysts hatch more slowly at temperatures below 25 °C, and above 33 °C cyst metabolism is irrevesibly stopped. E.E. Gusev (1991) based on the experiments proves that the best incubation results are observed at temperature of 30–31 °C when hatching is faster and intense. I.B. Bogatova (1980) notes that when the mass production of nauplii on fish farms (due to the climatic characteristics of Russia regions), the temperature of incubation solution generally ranged from 15–26 °C.

In the experiments there were tested the effects of three types of temperatures on hatching success: below the generally accepted optimum, within optimal range and above the optimum (Tab. 35).

In a first variant of the experiments the results of incubation at temperatures of 21 and 29 °C (cysts from Medvezhiye lake), 23 and 27 °C (dry cysts from Yarovoye lake), 24 and 28 °C (cysts from Kazakhstan lakes) were compared. In the first two cases, the result was better at lower temperature. In the third case, the analysis of 14 populations showed that the hatching percentage can both increase and decrease as the medium temperature rises. In general, the hatching percentage is almost similar at 24 hours of incubation for all lakes (40.5 and 41.2), and there is some difference at 30 hours of incubation (44.8 and 43.0).

In the second variant of the experiment, the hatching of cysts from Ulzhay and Medvezhye lakes were compared at temperatures of 25 and 29 °C. In both cases, the hatching rates were higher at a temperature of 25 °C.

In the third variant of the experiment, the affect of two close high temperatures of 29 and 31 °C was tested (cysts from lake Nevidim). It turned out that the temperature of 31 °C negatively influences the incubation result and reduces it by 1.7 times.

Thus, the investigations conducted allow concluding that the favorable incubation temperature is from 21 to 25 °C for the Artemia populations of the

Table 35. **Percentage of nauplii hatching at different temperature, %**

Place of sampling cysts	t, °C	Incubation time, h		Place of sampling cysts	t, °C	Incubation time, h	
		24	30			24	30
Nevidim	29	60.8	62.6	5	24	92.4	92.7
	31	36.5	38.1		28	91.4	91.6
B. Medvezhye 1	21	49.7	54.6	6	24	37.2	42.8
	29	33.4	35.0		28	39.4	41.6
B. Medvezhye 2	25	50.0	—	7	24	52.5	58.6
	29	34.5	—		28	74.9	74.9
Ulzhay	25	35.5	—	8	24	32.5	37.6
	29	29.7	—		28	24.5	26.9
B. Yarovoye, dry cysts	23	77.0	81.0	9	24	35.9	41.3
	27	73.1	74.8		28	24.7	27.0
Kazakhstan				10	24	44.0	49.2
Unknown lake:					28	49.0	51.2
1	24	10.2	15.3	11	24	39.0	44.3
	28	19.4	21.2		28	48.4	50.2
2	24	50.4	56.2	12	24	58.8	59.3
	28	48.2	50.1		28	49.2	52.1
3	24	20.4	25.3	13	24	49.8	55.7
	28	17.5	19.8		28	49.1	51.3
4	24	40.1	44.2	14	24	3.9	4.9
	28	39.6	41.3		28	1.5	2.3

Siberian lakes. Whereas, it shoud be noted that it is better to prolong the incubation period for 30 hours at lower temperatures of 21–23 °C as the hatching rate (embryo development) is delayed then.

7.1.2.3. The influence of light intensity

The illumination for cysts is essencial, at least during the first hours after complete hydration, to obtain maximal hatching percentage (Sorgeloos et al., 1986). The optimum light intensity for different populations varies and is determined by the thickness (Vanhaecke et al., 1981) and the color of cyst shell (Gilchrist, Green, 1960). This is evidenced by the fact that threshold light intensity for decapsulated cysts is significantly reduced, for example, it is from 100–500 to 20–100 Lux for San Pablo Bay cysts (Vanhaecke et al., 1981). It is recommended to use of light intensity of 1000 Lux (Lavens, Sorgeloos, 1987a) and 2000 Lux (Sorgeloos et al., 1986) in incubation techniques.

The experiments with two lighting modes: 1000 and 2000 Lux were conducted in order to test which light intensity is more suitable for the local population of cysts that mostly have a thick shell.

The experiments conducted in several replicates showed that hatching percentage was 45.0 ± 3.7 (C_v = 20 %) at higher illumination, and it was 31.9 ± 1.7 (C_v = 13 %) at lower illumination. Differences were reliable at high significance level ($r \leq 0.009$).

Thus, it is necessary to provide intensive light of 2000 Lux in order to improve incubation performance.

7.1.3. Determination of hatching efficiency

Hatching efficiency (HE) is the number of nauplii that can be produced from 1 g of dry cyst product under standard hatching conditions (24–48 hours, a solution of NaCl — 5–35 g/l, $NaHCO_3$ — 2 g/l, at temperature of 25–29 °C, illumination with light density of at least 1000 Lux, pH 8–8.5).

Average values of hatching efficiency for various geographical strains of Artemia are within 130–270 thousand ind./g. The best cyst product recorded was 300–330 thousand nauplii/g cysts (Sorgeloos et al., 1986). This criterion gives an idea about the cysts purity and their hatching capacity and depends on the sizes of cysts, i.e the larger cyst size, the less cysts per 1 g.

We have studied hatching efficiency of cysts from three geographical locations: Altay region (Bolshoye Yarovoye), Kurgan region and Kazakhstan (Tab. 36).

The number of cysts per 1 g of dry matter in the studied populations was within 116–199 thousand ind., which was closer to the lower limit of the average values for various geographical strains. This can be explained by the larger size of Siberian population cysts, and especially of cysts from Kazakhstan, the number of cysts in these populations is the lowest. The hatching efficiency was in the range 111–168 thousand nauplii per 1 g of dry cysts at hatching of more than 75 % and only 35.5 thousand nauplii/g of dry cysts at hatching of 30.6 %. Thus, this value is in very strong dependence on the quality of harvested cysts.

7.1.4. Determination of hatching rate

The hatching efficiency indicates on the time period from the start of incubation (cyst hydration) until release of nauplii from shells (hatching). The importance of defining this indicator is connected with the fact that Artemia nauplii are used as starter feed for fish larvae and crustaceans. Artemia nauplii grow very quickly that's why their size may go beyond the food availability, so it is advisable to remove the products as soon as possible at an earlier date, after reaching the maximum hatching percentage (T_{90} see below). It is known from the literature data (Sorgeloos et al., 1986) that the maximum percentage of hatching in different Artemia populations is observed after 18–42 hours of incubation. Therefore, it is desirable to determine by T_{90} by experiment.

Table 36. **Efficiency of nauplii hatching from cysts from different places of habitat**

Source of Artemia cysts	Efficiency of nauplii hatching, thousand of nauplii from gram of dry cysts	Hatching, %	The number of cysts per gram of dry matter
Bolshoye Yarovoye	153	87.6	175
Kurgan region	111–168	74.5–84.8	168–199
Kazakhstan	35.5	30.6	116

In the studies on hatching efficiency the following intervals were taken into account (Sorgeloos et al., 1986):

T_0 — incubation time until appearance of first free-swimming nauplii (for various populations is 14–20 hours);

T_{10} — incubation time until appearance of 10 % of total hatchable nauplii (mainly equal to 15–21 hours);

T_{90} — incubation time until appearance of 90 % of total hatchable nauplii (mainly equal to 20–37 hours);

$T_s = T_{90} - T_{10}$ — hatching synchrony measurement.

Table 37. **Parameters of hatching rate (hours) in three different populations at different temperature**

Source of Artemia cysts	t, °C	T_0	T_{10}	T_{90}	T_s
B. Medvezhye	22	10	11	20	9
	25	7	8	16	8
Soleniy Kulat	25	10	12	22	10
	28	9	11	18	7
Small lakes, Altai region	25	8	9	15	6
	28	6	7	12	5

The best result recorded was $T_s = 4.4–5.0$ hr, average results were in the range 5.3–10.0 hr (Sorgeloos et al., 1986).

It is known that the metabolic processes in the body are accelerated when temperature increases, so we would expect that the hatching rate will vary considerably depending on the incubation temperature.

The influence of temperature was determined by two variants: in the first variant, the hatching rate was compared at temperatures of 22 and 25 °C, and in the second variant, the hatching rate was compared at temperatures of 25 and 28 °C (Fig. 78).

In both variants, even slightly lower temperature slowed down the hatching rate. So, T_0 and T_{10} was from one to three hours more in the medium with lower temperature. The differences of T_{90} were more significant and made up 3–4 hours (Tab. 37). An important indicator of hatching synchrony T_s for the production of live food was in the range from 5 to 10 hours, and it was lower at higher temperature with difference of 1–3 hours.

Thus, when incubation medium temperature is decreased to 21–23 °C the percentage of hatching nauplii of Artemia cysts from local populations can be significantly increased, but at the same time the hatching synchrony is reduced, which is one of the important indicators of cysts quality.

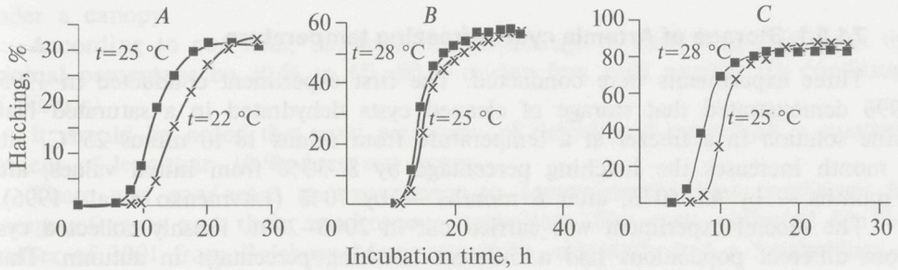


Fig. 78. Rate of Artemia cysts hatching at different temperature.
Cysts: *A* — inactivated from Medvezhye Lake (Kurgan region); *B* — from Soleniy Kulat Lake (Chelyabinsk region); *C* — from small lakes of Altai territory.

A comparative analysis of the rate of nauplii hatching from cysts collected from different populations (Medvezhiye, Soleniy Kulat, small lakes of the Altai Krai) at the same temperature of 25 °C showed that there is considerable dispersion of indicators (T_0 — from 7 to 10; T_{10} — from 8 to 12; T_{90} — from 15 to 22; T_s — from 6 to 10), and each population has a particular hatching rate. This fact indicates on the need to define the rate of hatching for each population in the industrial use of Artemia cysts.

7.1.5. Methods for activation of cysts

Artemia cysts collected in autumn usually have a low hatching percentage. They remain in a state of diapause, when embryos suspend their development at the gastrula stage. Their development is resumed only after activation.

Activation of cysts is an important moment of the biotechnology for Artemia nauplii using. The literature contains data about the effect on such cyst-activating factors as light (Vanhaecke et al., 1981), a constant magnetic field (Taneeva, Dolgopolskaya, 1974), ionizing radiation (Metalli, Ballardin, 1972), ultraviolet rays (Nimura, 1968; Bogatova, 1980), low temperature (Voskresensky, Khaydarov, 1967; Voronov, 1976; Bogatova, 1980; Vanhaecke, Sorgeloos, 1982), grinding eggs with sand (Bogatova, 1980), repeated hydration-dehydration cycles (Lavens et al., 1986), chemical substances included in incubation solution (Sato, 1966; Voronov, 1976, 1984; Bogatova, 1980; et al.) and others.

The effect of some factors increased the percentage of hatching, for example, in experiments using borax the hatching percentage was within 9 to 43 %, the effect of acetone increased the percentage of hatching nauplii by 15 %, baking soda — by 13 %, rinsing cysts with fresh water and salt water (10 % solution Na_2SO_4) — by 16–19 %, mechanical grinding with sand — by 13–20 % (Bogatova, 1980). Some factors as ultraviolet rays negatively affected on incubation results.

The results of these experiments showed that the test reagents have failed to achieve the desired level of hatching percentage. Under natural conditions, activation of the cyst occurs in autumn and winter as evidenced by the high percentage of hatching from the cysts collected in early spring. One of the methods for activation of cysts is based on simulated natural conditions.

7.1.5.1. Storage of Artemia cyst at freezing temperature

Three experiments were conducted. The first experiment conducted in 1995–1996 demonstrated that storage of cleaned cysts dehydrated in a saturated NaCl brine solution in a freezer at a temperature from minus 18 to minus 25 °C, after a month increases the hatching percentage by 8–30 % from initial values, after 4 months — by 43–50 %, after 6 months — by 70 % (Litvinenko et al., 1996).

The second experiment was carried out in 2000–2001. Freshly collected cysts from different populations had a different hatching percentage in autumn. Thus, in Ulzhay lake hatching percentage was 5 %, it was 22–31 % in lakes Vishnyakovskoye, Voskresenskoye and Medvezhiye, in lakes Novo-Georgievskoye and Trebushinoye — 55–56 %, and in lakes Filatov, Nevidim, Aktoban — 65–80 %.

These cysts were placed in a freezer at a temperature of –18 °C for cold activation. Fluctuations were observed in hatching percentage for 40–60 days. As the cysts were originally of different quality, the cold activation of these cysts occured differently (Tab. 38). However, a comprehensive analysis of these data led to the conclusion that, after every 10 days of storage of cysts in the freezer at temperature of –18 °C, hatching percentage increased by 2.6 %, except for some samples, for example, the hatching percentage even worsened with time of cysts collected from Vishnyakovskoye lake.

Table 38. **Parameters of nauplii hatching from cysts at action of cold and peroxide of hydrogen**

Source of Artemia cysts	Date of analysis	The percentage of hatching with activation	
		cold (–18 °C)	H_2O_2 (30 minutes)
B. Medvezhye	07.12.2000	31.0 (0)	51.6
	20.12.2000	36.8 (13)	53.2
	03.01.2001	40.2 (27)	54.0
	16.01.2001	46.0 (40)	58.3
Nevidim	07.12.2000	72.6 (0)	79.0
	16.01.2001	80.7 (40)	89.5
N.-Georgievskoye	07.12.2000	55.4 (0)	76.2
	16.01.2001	61.8 (40)	90.6
Trebushinoye	07.12.2000	55.9 (0)	78.1
	16.01.2001	66.8 (40)	80.9
Vishnyakovskoye	07.12.2000	21.9 (0)	65.3
	16.01.2001	17.6 (40)	56.3
Aktoban	07.12.2000	79.7 (0)	86.3
	16.01.2001	81.0 (40)	87.9
Filatovo	07.12.2000	64.6 (0)	77.5
	16.01.2001	71.3 (40)	85.7
Voskresenskoye	07.12.2000	29.3 (0)	79.5
	16.01.2001	49.9 (40)	73.2
Ulzhay	06.11.2000	4.5 (0)	22.3
	03.01.2001	16.7 (48)	28.9
	15.01.2001	20.5 (60)	40.3

Note. In brackets — quantity of days from the beginning of experience.

Cysts can be activated at temperatures from 0 to 5 °C. In this case, it is important to keep specific moisture level of cysts, since excess or insufficient water does not allow terminating the state of diapause of cysts. This can be achieved by suspending the cysts in a 10–12 % solution of NaCl for 1.5–2.0 hours, afterwards they are placed into gauze bags № 32 which are stored in wooden boxes or plastic bags. The boxes are capped and bags are tied up. In such conditions, cyst activation occurs after 60–80 days and hatching percentage can reach up 80–90 % (Voronov, 1976).

Activation of cysts dehydrated in brine NaCl also occurs during storage under natural winter conditions at temperatures from –10 °C to –25 °C bagged under a canopy.

According to our data, the hatching percentage of cysts improved from the original percentage by 30 % to 60–80 % during four cold months (in conditions of Siberia).

It should be noted that cold activation of dehydrated cysts with a moisture content of less than 10 % does not occur.

There was conducted an experiment to determine the best conditions for storage of cysts and their synchronous activation. The cysts collected in November of 2001 from Bolshoye Medvezhye lake, originally had a hatchability of 18 %. These cysts were stored at two different salinities and temperature regimes. There were 4 options in total:

1) NaCl concentration of 150 g/l, temperature of 5 °C;

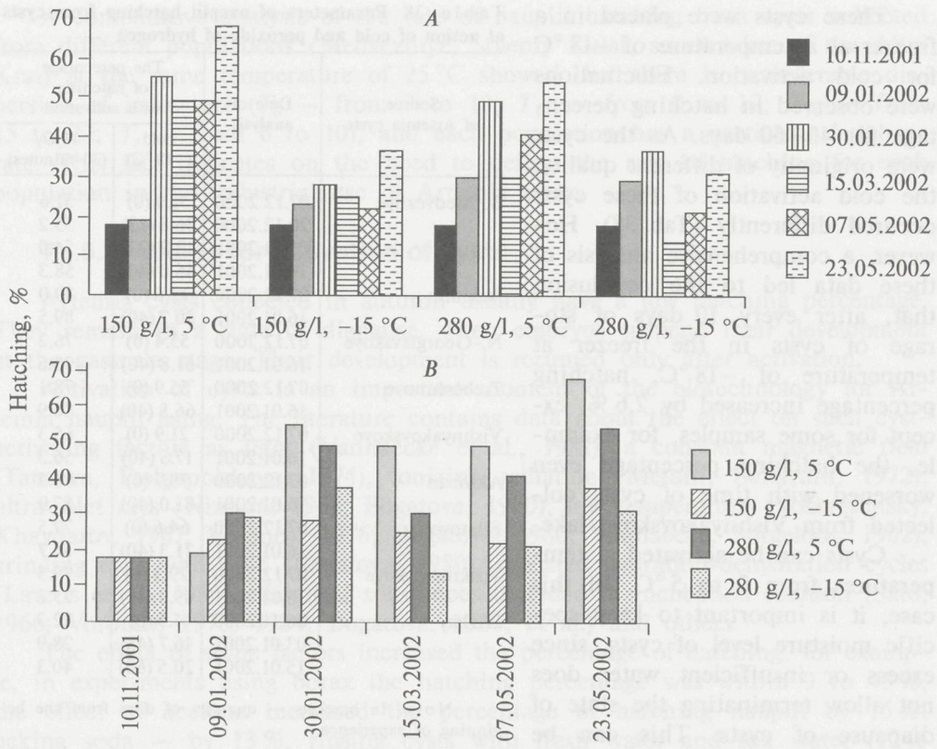


Fig. 79. Results of experiment to detect the storage conditions of cysts.

2) NaCl concentration of 150 g/l, temperature of –15 °C;
3) NaCl concentration of 280 g/l, temperature of 5 °C;
4) NaCl concentration of 280 g/l, temperature of –15 °C.

The experiment lasted 6 months. The results of the experiment are illustrated in Fig. 79.

A comparative analysis of the data collected in this experiment showed that the activation of cysts was the most successful in the first option, the results were slightly lower in the third option, and the results were the lowest in the second and fourth options of the experiment. The differences were reliable between options 1 and 2, 1 and 4, 2 and 3.

Thus, unactivated cysts should be stored at temperature of around 5 °C. It is better to suspend cysts in NaCl solution with concentration of 150 g/l.

7.1.5.2. Hydrogen peroxide activation of cysts

With embryonic development of the gastrula into nauplius stage, intensive redox processes take place and the embryo needs a lot of oxygen. Molecular oxygen enrichment of the medium is insufficient, so it becomes essential to

apply hydrogen peroxide H_2O_2 — a chemically active form of oxygen. There were developed two H_2O_2 — cyst treatment techniques (Bogatova, 1980; Bogatova, Shmakova, 1980): 1) activation with 3 % hydrogen peroxide prior to incubation; 2) incubation of cysts in 0.5–3.5 % sodium chloride solution supplemented with 1.3 mg/l–3 % hydrogen peroxide. According to I.B. Bogatova and Z.I. Shmakova (1980), both methods can improve "hatchability" of dry cysts from original hatching percentage of 3–5 % up to 60–80 % of the total.

Table 39. **Percentage of nauplii hatching from cysts, collected from 3 places of habitat at different duration of 3 % H_2O_2 action**

The duration of hydrogen peroxide, minutes	Filatovo	Nevidim	B. Medvezhye	B. Medvezhye*, test	
				1	2
0 (control)	17.1	32.5	35.4	66.9	50.7
10	60.1	48.9	38.9	72.1	50.9
15	**65.3**	**71.5**	47.2	**73.2**	**52.6**
30	62.5	70.6	**52**	69.1	31.7
45	54.5	68.4	49.1	70.3	32
60	54.3	64.3	48.3	68.2	32.7

Note. * Cysts have passed activation by a cold; the fat font designates the maximal parameters.

Our studies (Litvinenko et al., 2000) demonstated that before incubation, wet (dehydrated in brine solution) and frozen cysts are desirable to pre-heat at room temperature within 24-hours. Further keeping them in a warm temperature may result in reduced hatching percentage. Dry cysts stored at freezing temperatures are not required to be kept at room temperature as their hatchability slightly varied on the first day of warming as well as consecutive days.

Numerous experiments on hydrogen peroxide activation (Tab. 39) showed that the optimal time of affect of fresh 3 % hydrogen peroxide solution is 15–20 minutes, an increase and decrease of this time reduces hatching percentage. The analysis of all available data with hydrogen peroxide treatment showed that the hatchability of cysts seldom achieves such high values as stated by I.B. Bogatova and Z.I. Shmakova (1980). Basically, on the average of all data available (App. 55), the hatchability due to effectiveness of hydrogen peroxide treatment in Artemia cysts increased by 2.3 times (on average of 26 %) instead of 20 times as indicated by the above authors.

However, it should be noted that at lower hatching percentage, which is observed as a rule with summer and fresh autumn cysts, the peroxide treatment is more efficient (App. 56). If the initial "hatchability" value is less than 10 %, then this value can be increased by 37.2 % or 10.4 times on the average with the peroxide treatment. When the initial hatchability value is 10–20 % and 20–30 %, then hatching percentage can be improved by 38.1 %, respectively, or 3.2 and 2.6 times when H_2O_2-treated. As the initial hatchability value raises the effect of H_2O_2 treatment gradually decreases. The efficiency of activation (the difference between the experimental and control hatching percentage values) in gradation with hatching percentage to 40 %, mainly, differs significantly from the the gradation of this indicator for more than 40 %.

7.2. The current status of Artemia cysts stock and their commercial harvesting in Southwest Siberia in the period 2000–2004

7.2.1. Artemia cysts stock value and harvest outcome

The commercial exploitation of Artemia cysts in Siberia began in the early 1970's. In the period from 1978 to 1994 annual Artemia cysts harvests increased from 13.6 to 269.0 tons (Yasyuchenya, 2004) in Bolshoye Yarovoye lake in Altay area. This period in Tyumen region there were noted only two facts of harvesting in Siverga lake in 1978 and 1989 in the amount of around 25–35 tons. The total cyst stock, determined in 1989 in Medvezhiye lake in Kurgan region, was 156 tons, but official harvesting of Artemia cysts was not conducted in Kurgan and Omsk regions until 1995. In the last decade Artemia cysts harvested from southwest Siberian lakes are the main supply of starter feed for almost all fishing farms in the Russian Federation, moreover a considerable part of it is exported abroad. According to the literature data (Novoselova et al., 2000) the total cyst stock in the perspective lakes of the Altay area ranged from 0.8 to 3.8 thousand tons until the year of 2000. The dynamics of Artemia cyst commercial harvesting from 2000 to 2004, according to official statistical records, is shown in App. 57.

Generally, there were 16 harvesting companies in the region in 2000. The maximal amount of cysts for the entire period was 915 tons of dry weight (53 % of quota) in 22 lakes with a total area of 62 925 hectares. In 2001 there were 21 harvesting companies. 865 tons (47 % of quota) were harvested in 30 lakes with a total area of 70 806 hectares. In 2002, due to lower commercial interest in Russian cyst stocks (as a result of a large harvest of cysts on Great Salt Lake in Utah, USA), the number of harvesting organizations decreased to 9 as well as the number of lakes to 12 used for commercial harvesting. As a result, there were harvested 684 tons (52 % of quota). In 2003, in 9 lakes with a total area of 52 420 hectares there were extracted 826 tons of cysts, which made up 67 % of the allocated quota. In 2004, in 17 lakes with a total area of 58 168 ha there was harvested 893 tons of cysts or 58 % of the allocated quota.

Generally, over 5 year period the explored annual cyst stock ranged between 3338 to 7485 tons with an average amount of 4856 tons. The variability level of this feature was strong enough ($C_v = 32$ %).

The indicators of the total allowable catch (TAC) ranged from 1571 to 1976 tons with an average of 1825 tons in the given period. The amounts of the raw harvested cysts were from 684 tons to 915 tons with an average of 837 tons. The variability level of these indicators (C_v), which is equal to 9 and 11 % respectively, is related to the average and probably, more suitable for preliminary prediction of invertebrates catch than the amount of the stocks explored ($C_v = 32$ %) and the amount of allocated quota ($C_v = 17$ %).

Harvesting of cysts is closely dependent on the needs of the market. App. 58 shows that in 2000 and 2001, when there was the deficit in the Artemia cysts, the harvest was carried out most actively. The interest in this

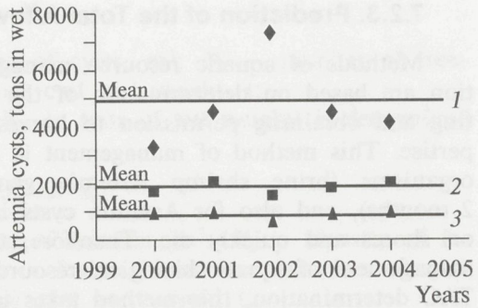


Fig. 80. Trends of parameters the TAC (total allowable catch), stocks of cysts and results harvesting of Artemia cysts.
1 — total stocks of cysts; *2* — TAC; *3* — volume of harvested cysts.

biological resource was accompanied by the search for new reserves, which resulted in an increase of explored reserves in 2002. This was due to the discovery of new Artemia producing lakes as well as due to detection of additional reserve stocks as benthic cysts. However, in the same year, the harvest was minimal due to sale of raw materials problems. In subsequent years, the volume of the harvested cysts became stable over 800 tons.

Fig. 80 shows the average volumes of harvested cysts were almost 6 times lower than the total of explored reserves and 2 times lower than the TAC value. The differences between the TAC and the volume of harvested product can be explained, besides market interest, by the lack of harvesting organization especially in shallow lakes as well as problems with the collection of benthic cysts, the volume of which is taken into account in determining the total reserves and the TAC.

App. 59 shows the commercially exploited lakes of Siberia with annual volumes of yield for the five-year period. Out of 37 lakes listed, Bolshoye Yarovoye and Kulundinskoye in the Altai territory, Ebeyty in the Omsk region, Bolshoye and Maloye Medvezhye in Kurgan region are the most important lakes for commercial harvesting.

13 kg/ha cysts in wet weight on average is yeilded from the area of 1 ha with the total stock of 80 kg/ha, which, in accordance with some researchers (Persoone, Sorgeloos, 1980), indicate a relatively high level of productivity of lakes.

7.2.2. A comparative analysis of the current and previous catches over 5 year period

The Artemia cyst catch has considerably increased in the last five years (App. 60). The water area of lakes used for harvesting increased twice mainly due to involvement of new lakes for harvesting purposes in particular Kulundinskoye lake which has a big area. Whereas the total explored reserves grew by only half, harvest amount — by 60 %, the value of TAC of cysts — only by 30 %. This is due to the fact for commercial exploitation were used not only highly productives lakes as Bolshoye Yarovoye, but also lakes with average productivity as well as highly productive shallow lakes which are difficult for catching benthic cysts. For this reason, the specific volume of cyst harvest dropped from 17 to 13 kg/ha, the productivity of lakes was from 135 to 80 kg/ha.

7.2.3. Prediction of the Total Allowable Catch of Artemia cysts

Methods of aquatic resource management existing in the Russian Federation are based on determination of the total stocks, the proportion of harvesting and obtaining permission to harvest after passing the state ecological expertise. This method of management is irrational and inefficient for short-cycle organisms (brine shrimp Artemia generation life time is not more than 2 months), and also for Artemia cysts inhabiting in shallow lakes accumulated on shores and quickly die. Therefore, there have been proposed two ways of management of aquatic biological resources: improved traditional method for the TAC determination, this method takes into account the stocks of benthic cysts and regulates the summer harvest and a completely new approach, developed in collaboration with Belgian and American scientists, based on preventing reduction of the Artemia population density below a certain minimum biologically acceptable level.

All these techniques are well described in the literature (Litvinenko et al., 2002, 2004, 2005). These methods are briefly presented below.

7.2.3.1. Traditional method

The method was developed by the group of scientists of the Altai area in the 80th–90th of the last century (Solovov, Studenikina, 1990; Studenikina, 1991; Evstigneev et al., 1997).

The main point of this method is to determine the total stock of cysts based on the hydrobiological researches in summer and autum period of Artemia generation: in August — for preliminary prediction and in the period of mortality of brine shrimp (October) to determine final prediction values.

Wherein, the cysts present in water column and in female ovisacs were taken into account in determination of preliminary prediction, sholine accumulation is additionally accounted for final prediction.

Improved traditional method

The main distinction of the improved traditional method (Litvinenko et al., 2002) from the previous one is that:

— additional preliminary prediction of catch and justification within the given prediction in summer (from June to September) is considered;

— preliminary catch prediction for a particular lake is based on the statistical value of the average volume of the total hatchable cysts reserves for the last 3–5 years, and the average cyst biomass in the previous years as well as the density of spring generation and trend of conditions for formation of hatchable reserves in the year of TAC estimation;

— total stock of cysts in lake includes planktonic cysts, shoreline cysts, cysts in female ovisacs and benthic cysts.

The assessment of the total stock of cysts is conducted on four components:

a) stock of free-swimming cysts (B_1, wet weight in tons) is determined according to the formula

$$B_1 = V_1 \cdot N_1 \cdot m,$$

where V_1 — volume of "inhabited" area of cysts, m^3; N_1 — number of free-swimming cysts, ind./m^3; m — individual cyst wet weight, t;

b) stock of cysts in female ovisacs (B_2, in tons of wet weight) is determined according to the formula

$$B_2 = V_2 \cdot N_2 \cdot R \cdot m,$$

where V_2 — volume of "inhabited" area of females, m^3; N_2 — density of females with cysts in ovisacs, ind./m^3; R — female brood size (number of cysts in oviscas), cysts/female; m — individual cyst wet weight, t;

c) stock of cysts accumulations on shore (B_3, in tons of wet weight) is determined according to the formula

$$B_3 = V_3 \cdot N_3 \cdot p \cdot m,$$

where V_3 — volume of cyst accumulations on shore, m^3; N_3 — number of wet cysts in 1 m^3 of volume, ind./m^3; p — purity of accumulations; m — individual cyst wet weight, t;

d) stock of cysts present on lake bottom (B_4, wet weight in tons) is determined according to the formula

$$B_4 = S \cdot N_4 \cdot m,$$

where S — area of lake, m^2; N_4 — density of benthic cysts, ind./m^2; m — individual cyst wet weight, t;

e) total stock of cysts is determined according to the formula

$$B = B_1 + B_2 + B_3 + B_4;$$

f) TAC of cysts (wet weight in tons) is determined according to the formula

for large lakes: $\text{TAC} = 0.6 \cdot B \cdot (1 + P)$,

for medium-sized lakes: $\text{TAC} = 0.5 \cdot B \cdot (1 + P)$,

for small lakes: $\text{TAC} = 0.4 \cdot B \cdot (1 + P)$,

where 0.4–0.6 is fraction of (40–60 %) cyst harvest; P — fraction of impurity in product.

When using the washing systems that allow reducing the impurity content of up to 8 %, then $P = 0.08$. In 1 m^3 of pure product (without impurities) is 100 billion ind./m^3 cysts that in wet weight corresponds to 900 kg.

7.2.3.2. Experimental method

A critical distinction between the experimental and the traditional method is shown schematically in App. 61.

This method of determining the TAC cysts is based on assumption of possibility of establishing minimum spring density of cysts or hatched nauplii, that would ensure the development of the Artemia populations at an optimum level and, as a result, the maximum yield of cysts. If the number of cysts and naup-

lii in spring will be below a certain value, it is necessary to inoculate the missing amount of cysts from the reserve stock.

According to the Laboratory of Aquaculture & Artemia Reference Center (Ghent University, Belgium), this method has been widely used in the recent years on Great Salt Lake in Utah (USA).

Based on the analysis of the first generation nauplii survival and growth of the Artemia population within season, the threshold concentration of cysts in water column in spring was established for this lake of 5.5 ind./l, accounting for survival in winter the autumn density of cysts in plankton should be at least 21–22 ind./l. In autumn, the density of plankton cysts is regulary monitored during harvest season on the lake, and harvest is stopped when density is reduced to 22 ind./l. This method, which allows not to create a reserve stock of cysts, is probably, the only suitable for large deep-water lakes as Great Salt Lake.

Taking into account that fact this method can be quite acceptable for relatively deep water lake Bolshoye Yarovoye in Altai Krai ($S = 67$ km^2; $H_{max} = 9$ m; $H_s = 4.4$ m).

In case with shallow Artemia lakes in Siberian region, the monitoring of the autumn density of planktonic cyst is not efficient, as major stocks of cysts are accumulated on shores and on lake bottom.

Therefore, the method for small Siberian lakes should be somewhat different. The point is that Artemia cyst harvest should be conducted without any restrictions on volume and time constraints but there should be created a reserve stock of cysts by harvesting organizations. The volume of a reserve stock is determined by scientific experts and agreed with the fishery inspection and Environmental Protection Services. It is necessary to perfrom inoculation from a reserve stock in essential amount if the density of cyst or nauplii is lower than a threshold value.

Dynamics analysis of the first generation brine shrimp density was performed in the period from April to June in 2001–2004 in 14 lakes of Kurgan and Omsk regions (see Sect. 4.2.3) to determine the minimal threshold of spring nauplii density in Siberian lakes. Fig. 58 of this Chapter shows that inspite of considerable number of the first generation nauplii (up to 5–6 thousand ind./l), only not more than 20 ind./l can survive to mature stage. It is known from the literature (Sorgeloos et al., 1986) that there should be from 5 to 20 nauplii per 1 litre for more effective functioning of Artemia lake biocoenosis. If the number of nauplii is more then, as a rule, they die due to insufficent food availability.

Thus, the optimum density is probably 20 nauplii per litre for brine shrimp population in Siberian biotopes.

If it is considered that planktonic cyst hatching percentage was 40 % on average in spring (according to the monitoring on Medvezhye, Nevidim, Vishnyakovskoye lakes), then the optimum density of cysts will be 50 ind./l.

In the relatively deep-water Bolshoye Yarovoye lake in the Altai area, the optimal cyst density in spring will probably be different, perhaps, closer to the minimum cyst density of 5.5 ind./l established for Lake Great Salt Lake.

A principally new methodology for determination of the TAC of cysts include the consecutive stages:

1. Hydrobiological studies on lake in middle of April to determine the number of "live" cysts and nauplii hatched.
2. Obtaining harvesting license in summer and autumn with no restrictions.
3. Harvest ban in the period of spring hatch of nauplii (April — May).
4. Organization of harvest in a timely manner and proper storage of cysts.
5. Formation of cyst stock for spring inoculation (at this stage in the amount of 50 ind./l).
6. Evaluation of residual cyst density in autumn and decision-making about the use of reserve stock of cysts.
7. Hydrobiological studies on lake in mid April to early May. If the number of "live" cysts is less than 50 ind./l or the number of nauplii is less than 20 ind./l, then cyst inoculation should be performed in missing amount from the previously made reserve.
8. Realization of excessive reserved cysts.

The adavantage of this method is:

a) maximal harvest of cysts, as a consequence, obtaining additional profit both for commercial organizations and for budgets of all levels;

b) possibility of artificial management of the first generation brine shrimp density and improvement of food supply;

c) possibility to collect cysts of good quality immediatly after shore accumulation without waiting for agreement with permitting agencies.

The disadvantage of this method is that it requires more labour resources and certain storage infrastructure, evaluation of their quality and, if necessary, inoculation performance in autumn.

This method of TAC determination anticipates observation of some requirements:

— conducting early spring hydrobiological studies to determine the spring density of cysts and nauplii;

— the study of population dynamics of the first generation brine shrimp;

— controling over the volume and quality of the collected stock of cysts, as well as the value of by-catch Artemia brine shrimp;

— placement and storage (for inoculation) stock of cysts, determination of indicators cysts quality (humidity, presence of impurities, hatching percentage);

— availability of equipment and personnel to carry out timely and effective inoculation of cysts in lake.

It is necessary to monitor the model lakes during appraisal of this method.

A fundamentally new method of determination the TAC of Artemia cysts (Litvinenko et al., 2002) was approved by the scientific and technical council of The Ministry of Agriculture of the Russian Federation, and approved by the Deputy Minister of Agriculture of the Russian Federation and recommended for testing on several model lakes of Kurgan, Omsk regions and the Altai area.

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7.2.4. Preliminary prediction of TAC of Artemia cysts

Table 40. **Five-year data on preliminary forecast of Artemia cysts TAC (total allowable catch) in lakes of Western Siberia**

Region	Forecast of Artemia cysts TAC, tons in wet				
	2002	2003	2004	2005	2006
Kurgan	335	280	300	365	365
Omsk	19	140	190	195	195
Novosibirsk	50	220	202	202	169
Altai	900	1230	1300	1210	1160
In total...	1304	1870	1992	1972	1889

Determination of preliminary prediction of TAC of Artemia cysts has been performed since 2002 on the basis of methods developed by FSUE Gosrybcenter (Litvinenko et al., 2002, 2004, 2005). Tab. 40 shows five year prognosis data issued with a year ahead.

The trend line, built on the basis of data on stocks of Artemia cysts, showed an increase in their reserves and the TAC from 2002 to 2003 related to the discovery of additional reserves — benthic cysts. In subsequent years, the value of the TAC fluctuated around the average value. According to these trend lines the TAC prediction for 2007 would be in the range 1600–2000 t (Fig. 80, 81).

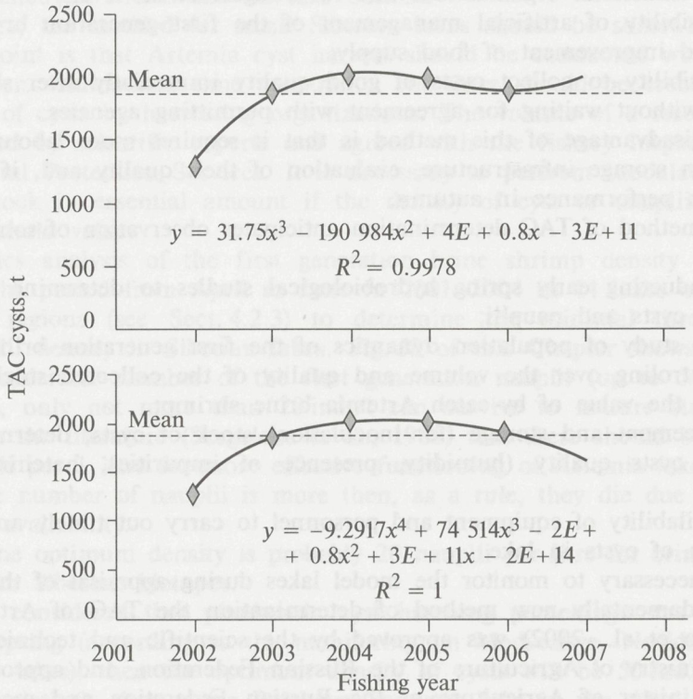

Fig. 81. Line of trend TAC (total allowable catch), of Artemia cysts with the forecast for 2007.

7.2.5. Predictiion of the TAC of Artemia biomass

It is necessary to know the seasonal average value of Artemia biomass and *P/B*-ratio when estimating Artemia biomass harvesting. App. 31 shows the average annual value of Artemia biomass on 27 lakes which were studies more extensively. The stock volume and the TAC of Artemia biomass were estimated using the biomass values, *P/B*-ratio equal to 10 (see Sect. 6.1.2.3), the proportion of withdrawal equal to 30 % (see Sect. 3.4.3).

Tab. 41 shows approximate data on the TAC volume of brine shrimp biomass in lakes of Western Siberia, Khakasia and Tuva. The total brine shrimp biomass in all lakes taking into account the production is around 160 thousand tons. The most productive lakes are Kulundinskoye lake with 67.7 thousand tons of shrimp biomass, Bolshoye Yarovoye — 24.6 thousand tons, Ebeyty — 11.2 thousand tons, Gorkoye (Novokluchi) — 8.2 thousand tons, Bolshoye Medvezhye — 7.6 thousand tons. The TAC on all lakes presented in the list will be 48 thousand tons of wet Artemia brine shrimp biomass with 30 % with-

Table 41. **Calculation of total allowable catch (TAC) of Artemia shrimps biomass in Western Siberia lakes**

Lake	*V*, million m³	The average biomass of Artemia shrimps, g/m³	Biomass production, t	TAC, t
1	2	3	4	5
Chelyabinsk region				
Tauzatkul	10.08	3.07	309.5	92.8
Soleniy Kulat	0.31	46.68	144.7	43.4
Oktyabrskoye	0.14	0.82	1.1	0.3
Kommunarskoye	0.10	3.20	3.2	1.0
Kurgan region				
Lavrusheno	0.37	7.37	27.3	8.2
Aslykul	1.50	9.81	147.2	44.1
Sulfatnoye	1.50	34.09	511.4	153.4
Vishnyakovskoye	1.76	35.65	627.4	188.2
Tibizkol	0.36	5.99	21.6	6.5
Setovo	1.75	2.40	42.0	12.6
Borki	4.95	3.48	172.3	51.7
Gashkovo	3.86	13.15	507.6	152.3
Aktoban	3.97	28.95	1149.3	344.8
Nevidim	5.03	31.41	1579.9	474.0
Trebushinoye	2.46	17.66	434.4	130.3
B. Kureynoye	2.23	38.77	864.6	259.4
Sobachye	0.17	7.24	12.3	3.7
Filatovo	11.84	12.49	1478.8	443.6
Umreshevo	0.96	8.11	77.9	23.4
Voskresenskoye	0.79	20.93	165.3	49.6
N.-Georgievskoye	2.03	12.66	257.0	77.1
B. Medvezhye	30.64	24.87	7620.2	2286.1
M. Medvezhye	14.48	21.08	3052.4	915.7
Cherdynskoye	1.75	36.98	647.2	194.1

Table 41 (continued)

1	2	3	4	5
Tyumen region				
Siverga	31.28	0.70	219.0	65.7
Solenoye 18 (Okunevskoye)	0.79	768	600.0	180.0
Omsk region				
Ebeyty	33.32	33.53	11 172.2	3351.7
Ulzhay	4.32	23.15	1000.1	300.0
Novosibirsk region[1]				
Gorkoye (Tsaritsino)	4.02	9.30	373.9	112.2
Lechebnoye	1.40	8.00	112.0	33.6
Gorkoye (Olkhovka)	20.00	12.00	2400.0	720.0
Chebakly	46.50	9.00	4185.0	1255.5
Karachi	1.89	4.60	86.9	26.1
Mikhaylovskoye	0.90	7.50	67.5	20.3
Gorkoye (Barabashi)	3.95	0.90	35.6	10.7
Gorkoye (Novoklyuchi)	6.88	119.00	8187.2	2456.2
Solenoye	3.60	1.60	57.6	17.3
Gorkoye (Konevo)	1.68	52.10	875.3	262.6
Ostrovnoye	5.00	5.30	265.0	79.5
Altay area[1]				
B. Yarovoye[2, 4, 5]	306.82	8.00	24 545.6	7363.68
Kulak-Sor	1.05	14.50	152.25	45.675
Dzhul-Suldy	1.55	11.50	178.25	53.475
Belenkoye	1.44	3.50	50.4	15.12
Petukhovo	6.00	21.50	1290	387
M. Yarovoye[2]	70.00	3.60	2520	756
Karatal	1.74	2.10	36.54	10.962
B. Gorchina	1.05	1.80	18.9	5.67
Chekurtuz	2.08	2.80	58.24	17.472
Krivaya Puchina	2.44	15.30	373.32	111.996
Petukhovskoye	9.80	2.10	205.8	61.74
Dzhomansor	2.09	1.90	39.71	11.913
Bauzhansor	6.60	3.70	244.2	73.26
Kurichye[2]	7.50	28.20	2115	634.5
Kulundinskoye[2–4, 6]	720.00	9.40	67 680	20 304
Malinovoye[7]	7.98	14.80	1181.04	354.312
Kuchukskoye[3, 4]	235.30	2.60	6117.8	1835.34
Tanatar 1[2]	9.90	19.10	1890.9	567.27
Solenoye (B. Gorkoye)[2, 5]	0.50	33.00	165	49.5
Mormyshanskoye[2]	2.80	20.70	579.6	173.88
Khakasia				
Tus	6.50	10.00	650	195
Tuva				
Svatikovo (Dus-Khol)	1.10	5.20	57.2	17.2
In total...			159 641.2	47 892.3

Note. The data on morphometric of Lakes and average biomass are taken from references: [1] Litvinenko et al., 2004; [2] Studenikina, 1986a; [3] Solovov et al., 1999; [4] Novoselova et al., 1996; [5] Solovov, Studenikina, 1992; [6] Vesnina, 2002a; [7] Vesnina, 2002b.

drawal. Similar values (namely brine shrimp production of 126.6 thousand tons, the amount of possible catch of 44.67 tons) were obtained with an approximate estimate of Artemia resource in the Western Siberia lakes by V.P. Solovov and T.L. Studenikina (1992), with the *P/B*-ratio value of 3 during the growing season and withdrawal volume of 50 % in large and medium-sized lakes, 75 % in small lakes (Studenikina, 1986a).

CONCLUSION

The Artemia biotopes distinguished by a wide range of mineralization from 34 to 299 g/l. The water of Artemia producing lakes are characterized by significant amounts of chlorides, sulfate, sodium, magnesium ions, with high hardness, from weakly alkaline to alkaline medium reaction, high concentration of organic substances, the presence of a sufficient amount of nutrients for photosynthesis. The growing season begins in spring for brine shrimp Artemia inhabiting shallow lakes, usually in the second half of April and ends in fall in the first decade of October and makes up an average of 180 days (in terms of degree-days it is around 2800–3400 °C). The optimum temperature for growth and reproduction observed on three summer months. The Artemia population endure unfavourable period in a state of diapause eggs or cysts.

The concentration of dissolved oxygen in water is mainly above the lower limit of normal existence of brine shrimp (1.5 mgO_2/l), but can be quite stressful when water temperature warmed up to 30 °C and above.

The species composition of phytoplankton is depleted in lakes, and from an environmental perspective is represented by halophiles and mesohalobs, is referred to nannoplankton by length-frequency, has a low density in a quantitive sense, and highly productive physiologically. The fauna of lakes is also very poor and has no more than 13 species. Artemia usually develops in monoculture at a salinity of more than 150 g/l.

In the Western Siberian lakes Artemia is attributed to *Artemia parthenogenetica* by reproduction mode which is typical for the population of the Old World. At the same time, there can sporadically be observed permament and temporary bisexual species of Artemia.

Cyst and nauplii sizes of the Siberian populations of Artemia slightly differ from the natural populations known in the world and occupy intermediate position in the amplitude of these indicators fluctuations. Males and females sexual dimorphism of Artemia is that females are significantly larger than males, mainly due to the length of the abdomen. Females have a greater abdominal length and wider head with more setae on furca. In turn, the males have greater distance between eyes, eye diameter and the ratio of furca length to abdomen.

The morphology of Artemia is greatly influenced by water salinity including sodium, magnesium, chlorides and sulphates. However, there was not

detected any reliable correlation between the indicators of brine shrimp length and salinity. Morphometric analysis of Artemia revealed particular trends associated with determination of values of number of parameters depending on the total mineralization of lakes. The structure of furca and abdomen are mostly affected by salinity. Due to high salinity the length of furca becomes smaller with fewer setae on furca, as well as width of abdomen, the distance between eyes, diameter of eyes, length of antenna and head width. The abdominal length as well as the ratio of abdomen to body length (index *ra*) rises in proportion to salinity.

Clustered analysis of brine shrimp morphometric parameters showed a clear division of the studied populations into three significantly differing groups according to the degree of mineralization of biotopes: high mineralized, medium mineralized and low mineralized.

Thus, the morphometric analysis, being one of the criterias to separate biological species, failed to reveal big differences between the Siberian populations, and between Siberian polulation and other European and Asian populations. The populations, which are remote on considerable distances (2200 km in-line pattern), joined into one cluster according to salinity but not geographical location. A comparative morphometric analysis of parthenogenetic and bisexual populations of Svatikovo and Tus lakes showed that females from Svatikovo lake differed significantly from the rest of parthenogenetic populations, and females from Tus lake did not differentiate from others.

A morphometric analysis of brine shrimp grown under experimental conditions in the same conditions of salinity has revealed the differences between the studied Artemia populations. Clustered analysis of brine shrimp growth parameters showed differentiation of all analyzed populations (our own and literature data) into two groups by geographic location of lakes. The first group consisted of the bisexual North and South American Artemia populations, the second group — parthenogenetic and bisexual European, Asian and African Artemia populations. The brine shrimps grown from cysts of the Siberian populations formed a general cluster with the Asian group of population by morphometric parameters.

Thus, the study of morphometric parameters of Artemia clearly showed the cumulative effect on the phenotype of genotype and the environment. Of all the morphometric characters which are the most informative, showing the effect of salinity, are length of furca and the number of setae on the furca. The parameters, showing the effect of genotype may possibly serve the ratio of abdomen to body length and the ratio of length of the cephalothorax to abdomen. The use of these parameters, to some extent, allows neutralizing the influence of environmental factors on the morphometric features of Artemia and focusing on the analysis of allometric variation.

Diploid chromosomes number of Artemia of 42 was established based on the cytogenetic analysis of 12 parthenogenetic populations in Southwest Siberian lakes. In this case, in addition to the modal number of 42 chromosomes, Artemia nauplii had single cells with tetraploid, haploid and aneuploid numbers. This data indicate on variability of chromosomes number of Russian Artemia

populations. In the description of the Artemia karyotypes from the Russian lakes there were found similarities in the number, size and type of chromosomes with the literature data (Mitrofanov et al., 1976). All chromosomes were telocentric.

DNA analysis allowed proving that all samples of the studied Russian populations of Artemia (including bisexual from Lake Tanatar) belong to one group. There was noted genetic similarity of the investigated samples of Russia, Kazakhstan, Turkmenistan and Mongolia, as well as to *A. urmiana* and *A. tibetiana*, i.e. Asian Artemia. Outgroup was formed by populations of *A. tunisiana* (Mediterranean), *A. persimilis* (South America) and *A. franciscana* (South and North America).

Based on the mitochondrial DNA sequences it was found by the nucleotide sequence method that bisexual Artemia population from Svatikovo Lake was absolutely identical to *A. sinica*, which formed a single cluster at the highest level of similarity. Thus, the population from Lake Svatikovo (Tuva) is genetically similar to *A. sinica*.

The obtained results on the identification of Russian Artemia populations indicate on need for further research to detect markers or group of markers related to the availability of one or another quality which directly or indirectly appear for each separate group.

In our opinion, the study of phylogenetic system of genus Artemia based on mitochondrial DNA sequences is the most promising.

In contrast to the population of the New World (Lenz, Dana, 1987), the Siberian Artemia populations have no distinct viviparous reproductive mode even in the first brood: the proportion of nauplii did not exceed 7 % of the total number of embryo. This leads to the characteristic of the Siberian population dynamics: spring peak at hatching from overwintered cysts, decrease by mid-summer and relatively low density by the end of the season. The main oviparous reproductive mode of the Artemia population is explained by the unstable conditions for the existence in shallow lakes (depth of 0.5–1.0 m) and interruption of the existence of the population when survives winters as cysts. The low percentage of viviparous reproductive mode is likely the result of natural selection in the changing hydration-dehydration cycles attributable to shallow lakes. Theoretically, (Lenz, Dana, 1987), in such populations high fecundity can be expected. However, the average values of offspring numbers per brood in the Siberian Artemia populations ranging 15–35 offsprings evidences moderate fecundity, the value of which is considerably lower than the values of fecundity of parthenogenetic strains from Turkey and India which is 50–110 offsprings per brood (Browne et al., 1984) and from China — 44–50 offsprings per brood (Quynh, Lam, 1987). In the Siberian populations only some brine shrimps had a high fecundity of up to 145–150 offsprings per brood.

In Siberian biotopes the maturation period for the first generation is 4–5 weeks which is due to lower temperature in spring, and for the summer generation it is restricted to 3–4 weeks. The maturation period under laboratory conditions is 2–3 weeks on average which corresponds to the experimentally established maturation period of 14–16 days (Sorgeloos, Persoone, 1975; Nimura, 1987), although there is data on earlier maturation period of 10 days in ponds (Quynh, Lam, 1987) and in laboratory culture (Wear, Haslett, 1987), as well as on later maturation period of 19 days for the Artemia population from China (Tobias et al., 1980).

Artemia cyst hatching in Western Siberia lakes was observed from the second half April, when water temperature warmed to 4–5 °C. One to three peaks of (meta) nauplii density were observed. As a rule, the first and the highest peak was registedred in April — May. It was the highest value. Adults and pre-adults started to show up almost in lakes from the end of May and early June onward.

Number of nauplii of the first generation in all lakes was above 20 ind./l, which according to data of some authors (Quynh, Lam, 1987; Sorgeloos et al., 1986), is quite sufficient for reproduction of the population. The highest density of nauplii, which was often observed (in some lakes up to 2196 and even 5164 ind./l) was the result of quick disruption of food supply in the lake, resulting in starvation death. Probably a low level of viviparous reproductive mode is explained by the low food supply in the supersaturated populations. The phytoplankton biomass in these lakes rarely exceeds 1 mg/l. Such a relationship between the food amount and reproduction mode has been noted in some studies (D'Agostino, 1980; Quynh, Lam, 1987). This probably explains the relatively low survival rate of the first generation brine shrimp. On average, only 15.1 % of brine shrimp survive to sexual maturity stage.

A reliable negative relationship between the number of nauplii and their survival found is probably due to the deterioration of feeding conditions in natural habitats with high population density. In spite of the high number of nauplii of the first generation, not more than 20 individuals per liter of water can usually survive to mature stage. Perhaps this brine shrimp density corresponds to the ecological capacity of the Siberian lakes.

A considerable fraction of Artemia cysts in the Siberian shallow lakes can be found on the bottom sediments. The sinking behavior of cysts was well described for cysts from Mono Lake (Thun, Starret, 1987) and, probably, a widespread phenomenon allowing the cysts to undergo a long activation stage on the lake bottom, but not on shore where is a high risk of mortality. However, at a salinity of more than 180 g/l there occurs decline of benthic cysts and increase in the number of planktonic cysts in the Siberian populations, which is probably due to the improvement of their buoyancy at high salinity.

The calculations showed that there are 850 thousand cysts at an average depth of 1 m per 1 m^2 in all lakes while 13 % of these cysts are present in the water column, and other 87 % are sedimented on the bottom. Taking into account mass of crude weight of cysts is 85 kg per 1 ha on average on all the Siberian Artemia population studied. Thus, the total mass of cysts in the Siberian lakes is quite high. Yet, a considerable fraction of cysts are unavailable for harvesting as they remain on the bottom sediment.

The analysis of the average seasonal values of Artemia biomass in 29 lakes for 10-years period showed that 10 lakes (35 %) were low productive (Artemia biomass was lower than 10 mg/l), 11 lakes (38 %) — medium productive (Artemia biomass was 10–30 mg/l), 7 lakes (24 %) — were highly productive (Ar-

temia biomass was 31–50 mg/l) and 1 lake (3 %) was very highly productive (Artemia biomass was more than 50 mg/l). Average Artemia biomass on all 29 lakes for all years of investigation was 23.3 ± 5.3 mg/l (C_v = 122 %).

The analysis of factors affecting the Artemia population density showed that the salinity is one of the critical factors. Thus, it was revealed that there is a close relationship between brine shrimp biomass and salinity of water, in particular, with chloride concentration, and increase in water salinity in lakes causes reduction in individual body weight of brine shrimp by raising body oblongness at unchanged length, does not affect the number of offsprings per clutch, but causes decrease in live birth and number of eggs per clutch, but increases number of clutches and number of planktonic and benthic cysts and does not affect their survivability.

The salinity ranging between 100–200 g/l is the optimum for growing Artemia biomass. The density of planktonic cysts is the highest at salinity of 140–180 g/l. The density of benthic cysts is the highest at salinity of 160–180 g/l. The salinity ranging from 50 to 270 g/l is favourable for cyst formation, the salinity lower than 50 g/l — for eggs, nauplii live birth are not almost observed at salinity above 220 g/l. The lakes of 2nd and 3rd classes with salinity from 70 to 250 g/l are the most productive, while the highest density of cysts are recorded in lakes of the 3rd class with salinity of 150–250 g/l.

The analysis of Artemia generations showed that the capacity of the first and second generations has no significant effect on the density of the third generation producing autumn cysts. Perhaps, in this case, the environment (salinity, temperature, dissolved oxygen concentration, food availability and etc.) has a prevailing effect on the capacity of the third generation. Therefore, even if the capacity of the first generation is very high, but it does not indicate that stock of cysts will be high, it is often vice verse, the first generation disrupt the food supply for the successive generations.

Obtained cofficients of correlation and determination between the stock of cysts and generation density indicate on average binding force when 30 % of total stock depend on the variability of the second and third biomass generations, and the standing crop for harvesting depend on the density of the third generation. Thus, if the total stock of autumn cysts can be predicted on the biomass of the second and third generations with some probability, but the stock of autumn cysts for harvesting can be predicted on the third generation biomass with acertain probability.

It was accepted to use the seasonal value of *P/B*-ratio of 3 for Siberian Artemia population for predictions works (Solovov et al., 2001). In our studies the values of *P/B*-ratio, obtained by various ways of estimations, were considerably higher. In this connection, it is recommended to apply the seasonal value *P/B*-ratio of 10, daily — 0.056 for estimation of the TAC of the brine shrimp biomass.

Artemia brine shrimps in Siberian lakes are active purifiers of water: they filter 154 % of water volume per day on average or the entire lake water volume is filtered within 15.6 hours. Extremely high filtration ability explains high water transparency in Artemia lakes.

The cysts, collected directly from the lakes, have various hatching percentage from 1.3 to 77.6 %, while the hatching rate of planktonic cysts ranges within 17–77.6 % with an average of 35.9 %, and of benthic cysts is from 1.3 to 57.5 % with an average of 19.1 %.

The experiments for determination of the optimal incubation conditions of cysts showed that in the absence of natural sea water it is better to apply salt solution of 5 g/l NaCl and 2 g/l $NaHCO_3$, since an increase in concentration of NaCl in the solution does not significantly improve the hatching percentage, and in some cases even reduces it. In addition, for Siberian Artemia populations as well as for populations of Kazakhstan the water temperature from 21 to 25 °C is more favorable for increasing the hatching percentage. At lower temperatures, since there is a delay in hatching effeciency, it is better to extend incubation time up to 30 hours. However, when the temperature of incubation medium is up to 21–23 °C, the hatching synchrony indicators, which are one of the most important indicators of the quality of cysts, are also decline.

Cold activation experiments showed that the storage temperature should be around 5 °C for deactivated cysts, in addition it is preferable to place cysts into NaCl solution in concentration of 150 g/l.

In general, for the five year period of investigations conduted in lakes of Western Siberia (2000–2004), the explored annual cyst stock ranged within the amount of 3338–7485 tons with an average of 4856 tons. Over the indicated period the TAC values were in the range from 1571 to 1976 tons with an average of 1825 tons, the volume of the actual harvested cysts ranged from 684 to 915 tons with an average of 837 tons. There are collected an average of 13 kg/ha cysts in crude weight from 1 ha area of all lakes. The cyst harvest closely depends on the market demand. The cyst harvesting was the most active in the period from 2000 to 2001 when there was deficiency in Artemia cysts. At present time, the TAC value of Artemia cysts in crude weight ranges around the average value of 1800 tons. Besides Artemia cysts, there are perspectives for harvesting Artemia shrimp biomass. An approximate estimation of brine shrimp biomass in lakes of Western Siberia, Khakasia and Tuva with an account of productions is around 160 thousand tons. With 30 % withdrawal, the TAC value will be 48 thousand tons of crude brine shrimp biomass.

THANKS

Numerous local and international organizations have contributed on various knowledge and methods related to Artemia, which we have compiled and used in this work. A major role in determining the methods of research played The Laboratory of Aquaculture & Artemia Reference Center (Ghent University, Ghent, Belgium) headed by Professor P. Solgeloos. We are grateful to B. Marden, manager of the research department of "Great Salt Lake Artemia Inc." (USA) for his assistance in the data gathering and sample collection as well as for his assistance in the development of experimental method of TAC determining. In genetic research, the assistance was provided by Dr. P. Bossir, under his guidance the work was carried out in the genetic center of Ostend (based on CLO-Sea Fisheries Department, Belgium). Most of the work was carried out on the basis of the Laboratory of Genetic Identification VNIRO (Moscow), under V.A. Barmintsev's leadership. Some of the material relating to the location of the lakes and stocks of cysts in them was provided by employees of the Altai and Novosibirsk FSBSI Gosrybcenter (formerly SibrybNIIproekt), namely, V.P. Solovov, L.V. Vesnina, T.L. Yasyuchenya, L.S. Viser.

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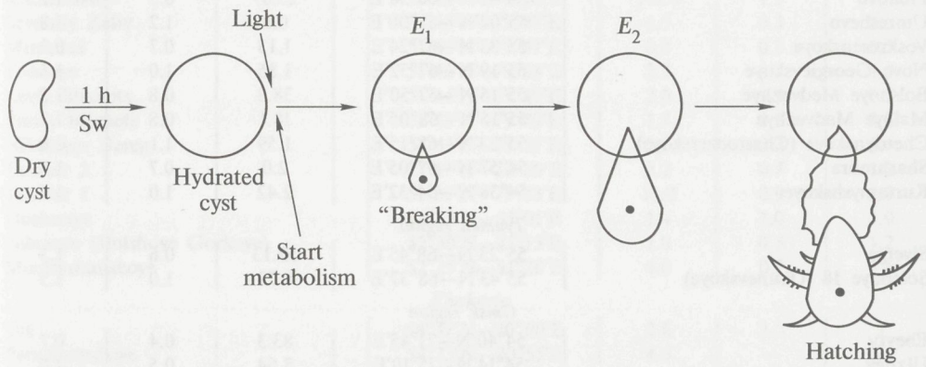
APPENDICES



App. 1. Development of Artemia cyst from incubation in seawater (Sw) until nauplius release (Sorgeloos et al., 1986).

E_1 — the first stage of embryo; E_2 — the second stage of embryo.

Appendix 2. **Geographical location of the basic Artemia lakes of Western Siberia and them morphometric characteristics**

Lake	Geographic coordinates	Square, km^2	Depth, m	
			average	max
1	2	3	4	5
	Chelyabinsk region			
Tauzatkul	54°25'N—61°53'E	12.6	0.8	1.2
Soleniy Kulat	55°00'N—61°57'E	0.52	0.6	1.1
Oktyabrskoye	54°27'N—62°42'E	0.2	0.7	1.2
Kommunarskoye	54°21'N—62°53'E	0.13	0.8	1.1
Okunevoye	54°38'N—63°06'E	0.75	0.8	1.2
Sosnovskoye	54°29'N—62°42'E	1.19	1.5	2.5
Bersenevskoye	55°05'N—62°07'E	1.7	1.0	1.6
	Kurgan region			
Lavrusheno	55°03'N—61°59'E	0.61	0.6	1.0
Aslykul	54°58'N—62°07'E	1.5	1.0	1.5

Appendix 2 (continued)

1	2	3	4	5
Sulfatnoye	54°51'N—62°29'E	1.0	1.5	1.8
Vishnyakovskoye	54°44'N—63°48'E	2.06	0.8	1.8
Tibizkol	54°46'N—63°41'E	0.52	0.7	1.1
Setovo	54°32'N—63°59'E	0.97	1.8	2.2
Borki	54°25'N—64°13'E	3.81	1.3	2.2
Gashkovo	54°42'N—64°32'E	3.51	1.1	2.0
Svetlenkoye	55°16'N—66°15'E	0.3	0.5	0.8
Aktoban	55°18'N—66°19'E	6.61	0.6	0.7
Nevidim	55°08'N—66°55'E	7.18	0.7	1.6
Trebushinoye	55°02'N—66°56'E	3.08	0.8	1.5
B. Kureynoye	54°56'N—66°56'E	3.71	0.6	1.6
Sobachye	54°57'N—66°58'E	0.42	0.4	0.6
Filatovo	54°45'N—66°58'E	23.67	0.5	1.1
Umreshevo	55°02'N—67°00'E	0.8	1.2	1.8
Voskresenskoye	55°33'N—67°24'E	1.13	0.7	0.9
Novo-Georgievskoye	55°19'N—67°52'E	1.85	1.0	1.5
Bolshoye Medvezhye	55°15'N—67°50'E	38.3	0.8	1.3
Maloye Medvezhye	55°15'N—68°05'E	18.1	0.8	1.2
Cherdynskoye (Chastoozerskoye)	55°23'N—68°15'E	1.59	1.1	2.0
Shashmura	54°57'N—67°05'E	2.0	0.7	1.5
Kurtamyshskoye	54°38'N—64°32'E	2.42	1.0	1.5
Tyumen region				
Siverga	55°23'N—68°45'E	52.13	0.6	1.3
Solenoye 18 (Okunevskoye)	55°43'N—68°37'E	0.79	1.0	1.5
Omsk region				
Ebeyty	54°40'N—71°45'E	83.3	0.4	0.7
Ulzhay	54°14'N—75°10'E	8.64	0.5	1.0
Novosibirsk region				
Gorkoye (Tsaritsino)	55°00'N—76°22'E	6.70	0.6	0.7
Lechebnoye	54°45'N—76°30'E	2.8	0.5	0.9
Gorkoe (Olkhovka)	54°45'N—76°35'E	25.0	0.8	2.0
Chebakly	54°38'N—76°55'E	31.0	1.5	2.0
Karachi	55°20'N—77°00'E	2.7	0.7	1.0
Mikhaylovskoye	54°27'N—77°15'E	1.5	0.6	0.7
Gorkoye (Barabashi)	54°12'N—77°22'E	7.9	0.5	0.7
Gorkoye (Novoklyuchi)	54°10'N—78°00'E	6.88	1.0	2.5
Solenoye	53°28'N—78°05'E	2.0	1.8	2.0
Gorkoye (Konevo)	54°15'N—78°50'E	2.8	0.6	1.2
Ostrovnoye	54°50'N—78°55'E	10.0	0.5	0.8
Altay area				
Bolshoye Yarovoye	52°50'N—78°41'E	66.7	4.6	9.5
Kulak-Sor	53°15'N—78°13'E	2.1	0.5	1.1
Dzhul-Suldy	53°21'N—78°15'E	3.1	0.5	1.1
Bura	52°40'N—78°26'E	4.2	—	—
Belenkoye	52°59'N—78°57'E	2.4	0.6	1.2
Petukhovo	52°06'N—79°09'E	4.0	1.5	2.4
Maloye Yarovoye	53°04'N—79°10'E	35.0	2.0	3.9
Karatal	51°51'N—79°11'E	2.9	0.6	0.9
Bolshaya Gorchina	51°56'N—79°11'E	2.1	0.5	0.8
Chekurtuz	52°24'N—79°19'E	5.2	0.4	0.8

Appendix 2 (continued)

1	2	3	4	5
Krivaya Puchina	52°26'N—79°21'E	6.1	0.4	1.0
Petukhovskoye	52°16'N—79°21'E	14.0	0.7	1.0
Dzhomansor	52°48'N—79°25'E	1.9	1.1	1.5
Bauzhansor	52°44'N—79°27'E	11.0	0.6	0.9
Kurichye	52°42'N—79°29'E	15.0	0.5	0.9
Kulundinskoye	53°10'N—79°30'E	720.0	2.0	3.6
Dunai	52°03'N—79°30'E	10.2	1.1	2.0
Vshivka	51°46'N—79°39'E	5.8	0.6	1.2
Lomovoye	51°43'N—79°42'E	1.4	0.5	0.9
Gornastalevo	51°56'N—79°42'E	12.0	0.5	0.8
Malinovoye	51°44'N—79°44'E	11.4	0.7	2.3
Burlinskoye	53°08'N—79°25'E	31.6	0.9	1.5
Kuchukskoye	52°42'N—79°46'E	181.0	1.3	1.8
Severniy Zaliv	51°43'N—79°47'E	1.5	0.3	0.5
Ministral	51°45'N—79°47'E	0.9	0.3	0.5
Yodnoye	51°42'N—79°48'E	2.7	0.8	1.5
Leviy Bliznets	51°44'N—79°49'E	2.0	0.3	0.5
Praviy Bliznets	51°43'N—79°49'E	1.8	0.3	0.5
Nikolayev Bereg	51°43'N—79°51'E	2.5	0.3	0.6
Tanatar 2	52°17'N—80°59'E	2.2	0.7	1.0
Tanatar 1	51°37'N—79°53'E	11.0	0.9	1.9
Dushnoye	52°53'N—81°01'E	1.4	1.0	1.9
Solenoye (Bolshoye Gorkoye)	52°30'N—81°15'E	1.0	0.5	1.2
Mormyshanskoye	52°25'N—81°28'E	4.0	0.7	1.4
Khakasia				
Tus	54°37'N—90°00'E	2.6	2.5	7
Pervomayskoye	54°33'N—90°55'E	4.5	—	—
Tuva				
Svatikovo (Dus-Khol)	51°32'N—94°25'E	0.55	2.0	3.4
Cheder	51°15'N—94°40'E	6.75	0.8	1.8
Total:				
79 lakes of Western Siberia		1567		
4 lakes of Khakasia and Tuva		14.4		

Appendix 3. **Climatic characteristic of Western Siberian area of Artemia (within Russia — from Ural Mountains to Altai) and temperature in Artemia lakes**

Parameter	Units	min — max
Average annual air temperature*	°C	0.1–1.8
Average January air temperature*	°C	minus 15.7 — minus 19.7
Average July air temperature*	°C	18.3–18.9
The sum of air temperatures over 10 °C	°C	1900–2400
Heating water to 4–5 °C	—	April 15–30
Cooling water to 4–5 °C	—	October 1–20
Duration of the growing season	days	180
The amount of water temperatures over 4–5 °C (during the growing season)	°C	2800–3300

Note. * According to A.P. Slyadnev (1965).

Appendix 4. **Average long-term parameters of chemical water composition of the investigated lakes during vegetative season, mg/l**

Lake	pH	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Total water hardness, suH/l	Ca^{2+}	Mg^{2+}	$Na^- + K^-$	Σ_i	BOD_5, mgO_2/l	PO, mgO/l
1	2	3	4	5	6	7	8	9	10	11	11	13
						Kurgan region						
M. Medvezhye												
M	8.0	89.2	527	93 002	21 701	1006	745	10 852	51 055	176 395	2.8	77.8
min	7.7	25.2	284	62 125	9605	760	400	7873	30 961	115 281	1.4	47.3
max	8.3	162	1078	120 700	30 525	1370	1198	13 703	76 420	235 990	4.1	159
B. Medvezhye												
M	7.9	87.2	532	92 417	21 400	1005	740	10 842	50 655	176 387	2.6	78.3
min	7.7	23.3	321	61 250	9605	760	400	7873	30 961	115 281	1.6	46.5
max	8.3	162	1078	120 900	29 779	1370	1169	13 454	72 338	235 990	3.2	160
Nevidim												
M	8.3	108	550	49 833	23 512	585	349	6899	29 053	108 371	5.7	48.3
min	7.9	32.4	403	25 114	12 457	344	170	4060	15 155	57 432	3.2	35.4
max	8.6	180	976	79 875	43 227	805	601	9424	49 211	167 051	12.6	65
Vishnyakovskoye												
M	8.2	106	509	65 259	44 263	588	368	6907	50 429	167 840	3.2	46.4
min	6.8	33	272	32 646	12 776	285	190	3350	21 770	71 037	8.9	51.4
max	8.4	228	787	88 750	72 045	850	701	10 093	72 754	244 711	5.2	60.0
Aktoban												
M	8.4	113	389	69 641	19 735	751	638	8744	37 802	137 562	1.4	31.1
min	8.1	40	317	29 994	7118	320	240	3745	16 355	60 356	2.9	39.0
max	8.6	216	451	92 300	29 539	1050	1403	12 494	54 064	186 689	4.5	47.4
B. Kureynoye												
M	8.3	165	678	55 279	12 197	618	343	7687	27 513	103 566	2.4	33.4
min	7.8	63.3	390	29 647	1297	220	140	2432	15 361	57 382	3.1	49.5
max	8.6	258	1267	79 165	21 854	880	601	10 518	41 918	154 637	3.6	61.1
Trebushinoye												
M	8.3	63	543	42 666	11 994	544	850	6119	20 347	79 173	1.3	52
min	7.8	0	269	23 430	1633	310	541	3441	11 426	49 264	5.1	68.1
max	8.6	126	1464	54 670	17 291	800	1403	9424	28 950	109 064	10.3	97.0
Filatovo												
M	8	19	236	63 153	8628	813	2113	8699	26 223	108 582	1.1	41.9
min	7.9	2.2	172	29 992	3602	376	1220	3832	13 552	53 183	5.9	51.0
max	8.1	48	415	95 495	14 649	1160	2705	12 951	42 371	167 796	13.1	67.3
Gashkovo												
M	8.2	98	527	54 108	14 546	369	274	4315	36 384	108 081	2.7	52
min	7.1	0	320	28 411	7848	176	190	2024	19 090	57 941	8.5	54.7
max	8.6	210	671	81 650	21 133	485	401	5758	52 923	162 007	16.8	59.9
Setovo												
M	8.7	261	931	30 250	9072	222	60	2663	19 579	62 816	0.2	12
min	8.5	0	683	14 038	6661	84	40	965	11 085	33 526	3.5	24.6
max	8.8	480	1061	42 600	12 008	350	92	4237	23 888	78 365	8.4	36.6
Umreshevo												
M	8.2	132	469	34 657	17 549	492	402	5739	19 947	78 897	0.8	36.4
min	7.7	0	244	25 268	8943	280	66	3365	13 548	52 371	5.3	41.3
max	8.5	492	1061	42 600	24 958	720	802	8269	25 613	100 088	12	44
Shamelya												
M	8.4	215	699	73 115	17 269	534	221	6356	41 847	141 080	2.3	31
min	7.9	44	400	27 354	5763	280	92	3349	17 598	60 104	4.4	46.8
max	8.9	456	1541	106 500	36 503	850	601	10 250	66 231	212 842	7.4	78.0
Sobachye												
M	8.7	263	703	68 880	42 677	657	269	7824	58 086	178 632	5.7	74.7
min	8.6	88	488	25 619	11 047	240	100	2857	21 770	70 830	3.1	43.6
max	8.8	480	1220	85 200	77 329	870	461	10 300	72 022	242 324	8.3	132
Lavrusheno												
M	7.5	3	158	79 132	4548	1131	2982	11 625	27 636	126 612	1.5	19.5
min	7	0	98	27 585	1368	490	235	4528	7664	43 668	1.2	8
max	8.1	13	244	134 900	9606	1740	7916	20 124	52 017	220 891	1.8	31.1
Voskresenskoye												
M	8.2	15.4	172	35 095	3888	426	1433	4318	15 288	60 484	2.0	42.3
min	8.2	9.1	160	24 700	1825	305	1073	3058	10 795	42 446	1.7	35.3
max	8.4	24	196	46 150	5156	565	1804	5776	19 240	77 871	2.6	53
N.-Georgievskoye												
M	8.8	313	1236	38 075	10 192	212	66	2561	25 902	79 454	5.1	51.3
min	8.7	186	1034	32 986	8669	170	60	2086	23 020	68 134	2.9	47.2
max	8.8	480	1342	42 600	12 540	240	70	2882	27 439	86 060	8.4	53.7
Aslykul												
M	7.9	0.95	396.5	26 828	7734	402.5	270.5	4730	12 356.5	52 317	3	30.8
min	7.8	0	335	18 951	5657	280	180	3295	9069	37 490	3	22
max	8	1.9	458	34 706	9811	525	361	6165	15 644	67 143	3	39.7
Cherdynskoye												
M	8.4	126	652	79 800	15 889	550	172	6583	47 906	151 136	2.4	61.1
min	8.4	89	616	46 677	7391	300	80	3599	28 420	86 951	1.5	48.5
max	8.5	168	682	104 725	21 854	760	250	9090	61 196	197 899	3.6	78.3

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Appendix 4 (continued)

1	2	3	4	5	6	7	8	9	10	11	11	13
Borki												
M	9.1	575	2335	19 833	13 352	28	46	295	20 294	56 733	3.5	31.9
min	9.1	378	1916	15 091	10 038	15	40	158	15 237	43 180	1.9	24
max	9.2	960	2581	23 430	16 330	40	60	449	24 364	67 863	6.8	37.5
Tibizkol	8.5	114	728	35 060	10 951	385	94	4625	19 961	71 555	2.2	50.5
Shashmura	8.8	96	464	88 750	61 478	1120	802	13 133	61 428	226 151	2	52
Lake N 1	8.5	144	439	93 720	53 313	1170	601	13 862	59 685	221 765	15.6	48
Kurtamyshskoye	9.5	1452	5211	11 117	19 529	5	3	59	19 527	56 898	4.5	69.2
Tyumen region												
Solenoye 18 (Okunevskoye)												
M	8.1	92	446	46 845	6683.4	491	798	5484	22 674	82 701	7.8	54.5
min	8	0	305	39 895	1537	250	366	1581	16 728	64 675	3.9	35.2
max	8.3	240	915	58 220	9606	670	2405	7904	27 209	103 885	14	99
Siverga												
M	8.5	232	777	27 964	12 184	177	83	1987	17 560	60 529	6.4	45.4
min	8.2	83.6	671	12 985	864	104	56	1230	2619	30 150	1.7	30.2
max	8.7	420	1037	35 500	43 227	240	120	2858	38 985	121 072	12	67
Chelyabinsk region												
Kommunarskoye												
M	8.25	35.7	200	33 404.5	3950.5	380	786	4143.5	14 909	57 427	4.7	43.8
min	8.1	11.4	180	31 309	2882	360	401	3666	14 509	55 862	1.1	39.6
max	8.4	60	220	35 500	5019	400	1172	4621	15 309	58 992	8.3	48
Okunevoye	7.9	144	524	53 250	7684	440	300	5168	28 368	95 438		
Soleniy Kulat												
M	7.7	18	271	73 636	5485	1058	3482	11 466	26 328	120 685	8.4	50.7
min	7.1	0	232	39 292	1921	570	401	5958	14 505	64 583	2.2	44.8
max	8.1	72	317	110 050	12 488	1600	10 086	16 902	42 233	185 019	19.2	55.4
Sosnovskoye	8.2	336	878	46 150	5283	500	200	5958	21 518	80 323	—	—
Bersenevskoye	7.8	240	195	53 250	10 566	650	1002	7296	24 863	97 412	—	—
Oktyabrskoye												
M	8.3	48.5	474	28 744	6389	333	183	4128	14 374	54 334	4.6	25.7
min	8.2	36	183	18 249	1921	206	70	2456	10 545	37 699	1.1	4
max	8.6	57.2	772	35 500	11 407	440	401	5107	18 682	68 260	10.8	46.4
Tauzatkul												
M	8.2	40	198	22 151	4251	245	330	2785	10 962	40 720	6.1	25.1
min	7.6	0	122	16 143	1460	180	200	1982	7440	27 623	1.8	16.2
max	8.8	120	256	26 171	7453	297	450	3334	13 808	51 434	12	31.2
Altay area												
B. Yarovoye	—	—	311	105 000	480	874	468	10 300	52 100	171 700	—	—
Kulundinskoye	8.5	—	1717	35 835	19 270	360.5	57	4349	31 854	92 350	—	59.1
Malinovoye	8.2	—	1401	110 670	47 740	38.4	54	434	94 504	254 975	—	69.4
Omsk region												
Ulzhay												
M	8.3	158.8	533	39 937	9474	365	241	4098	23 006	77 412	2.25	42.3
min	7.9	55.9	384	27 477	576	250	100	2979	12 144	44 763	1.3	33.3
max	8.5	240	732	57 670	17 697	500	661	6007	34 634	114 831	3.2	50
Ebeyty												
M	8.1	57	655	84 755	63 292	543	464	6315	73 736	229 193	4.5	78.3
min	7.8	0	390	39 433	6710	228	205	2650	40 623	130 473	1.6	46.5
max	8.6	150	1098	184 600	106 999	920	1002	11 029	123 234	371 133	7.6	123
Khakasia												
Tus	8.5	480	1281	29 820	59 557	800	200	9606	30 291	131 236	6.4	24.0
Pervomayskoye	9.1	720	1342	14 200	34 582	200	50	2402	22 218	75 513	8.0	38.4
Tuva												
Svatikovo (Dus-Khol)	7.7	135	647	95 963	16 426	1190	289	14 295	44 978	172 734	2.7	51.5
Cheder	9.3	960	1220	19 880	57 636	200	120	2359	37 076	119 251	6.0	36.0

Note. BOD_5 — biological oxygen demand for 5 days; PO — permanganate oxidation.

Appendix 5. **Ratio actual salinity for month to average seasonal values**

Month	M	σ	C_v	Month	M	σ	C_v	Month	M	σ	C_v
I	1.28	0.36	28	V	0.78	0.12	15	IX	0.89	0.51	57
II	1.09	0.28	25	VI	0.92	0.08	9	X	1.12	0.11	10
III	0.75	0.42	56	VII	1.05	0.06	6	XI	0.98	0.16	17
IV	0.29	0.34	116	VIII	1.04	0.20	19	XII	1.07	0.15	14

Appendix 6. **Total salinity in lakes for the ten years' period of researches, g/l**

Lake	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	M	σ	C_v
B. Medvezhye	110	145	143	225	185	**225**	**198**	**167**	**165**	**195**	176	37	21
M. Medvezhye		145	143	225	186	**235**	**198**	**175**	**156**	**194**	184	33	18
Nevidim	75	90	135	159	128	126	**101**	**68**	**66**	**79**	103	32	32
Vishnyakovskoye			199			192	**112**	68	**83**	102	126	56	44
Ulzhay	54	49	63			143	109	**89**	92	105	88	32	36
Ebeyty	210	144	250				288	**193**	**154**	**172**	202	52	26
Shamelya	161	147	146	203	171	130	96	61			139	44	32
Solenoye 18	83	66				99	97	88			87	13	15
B. Kureynoye		81	102	116	126	148	127	55	45	65	96	36	38
Trebushinoye	47	68	84	96		101	94	50	38	49	70	25	35
Sobachye		180	215			231	157	77			172	61	35
Siverga	64	54			64	115	64	45			68	24	36
Aktoban			162		180	171	89	**60**	57	152	124	54	43
Filatovo			73		120	160	152	66	50		104	47	45
Gashkovo			119	154	119	107	78	53			105	35	34
Setovo			74		73	67	58	37			62	15	25
Umreshevo			67		80	95	96	49			77	20	26
Okunevoye			91								91		
Lavrusheno			176		213		59	48			124	83	67
Soleniy Kulat			159	116	178	99	85	66	54	62	102	46	45
Voskresenskoye						75	67	43			62	17	27
N.-Georgievskoye	77				74	100	100	65	68	95	83	15	18
Sosnovskoye			76								76		
Bersenevskoye			92		106						99	10	10
Lake 1						211					211		
Kurtamyshskoye							54				54		
B. Yarovoye								172			172		
Kulundinskoye								95			95		
Malinovoye								263			263		
Aslykul							69	40			55	21	38
Cherdynskoye						189	200	115	117	254	175	59	34
Shashmura						217					217		
Borki						70	61	47			59	12	20
Kommunarskoye						56	53				55	2	4
Oktyabrskoye						54	65	41			53	12	23
Tauzatcul						41	49	30			40	10	24
Tibizkol							74		59		67	11	16
Tus							133			73	103	42	41
Svatikovo										155	155		0

Note. Averages according to monitoring are shown by fat font.

Appendix 7. **Species composition of phytoplankton in investigated salt lakes**

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		Siverga	Okunevskoye	Cherdynskoye	N.-Georgievskoye	B. Medvezhye	M. Medvezhye	Filatovo	Nevidim	Umreshevo	B. Kureynoe	Trebushinoye	Sobachye	Vishnyakovskoye	Aktoban	Voskresenskoye	Gashkovo	Setovo	Borki	Shamelya	Lavrusheno	Aslykul	Oktyabrskoye	Soleniy Kulat	Tauzatkul	Ulzhay	Ebeyty
Bacyllariophyta																											
Melosira varians Ag.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Aulacosira italica (Ehr.) Simonsen		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cyclotella caspia Grun.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chaetoceros Muelleri Lemm.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Achnantes brevipes Ag.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Achnantes hauckiana Grun.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Amphora coffeaeformis var. *transcaspica* Boye P.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Amphora veneta Kutz.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Amphiprora ornata Bail.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia angustata (W. Sm.) Grun.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia punctata var. *minutissima* Por.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia longissima (Breb.) Ralfs		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia frustulus (Kutz.) Grun.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia vitrea var. *salinarum* Grun.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia obtusa var. *nana* V. H.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia thermalis Kutz.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Navicula sp.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Navicula salinarum Grun.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Synedra tabulata var. *fasciculata* (Kutz.) Grun.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Stauroneis salina W. Sm.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chlorophyta																											
Carteria salina Wisl.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ankyra judayi (G.M. Smith) Fott		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Korschikoviella gracilipes (Lambert) Silva		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chlamidomonas Reinhardii Dang.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chlamidomonas globosa Snow.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Coelastrum astroideum De – Notaris		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Dunaliella salina Teod.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Dunaliella viridis Teod.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Appendix 7 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Pedinomonas tenuis Massjuk	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Spermatosopsis exsultans Korsch.	–	–	–	+	–	–	+	+	–	+	–	–	+	–	–	+	+	+	+	–	–	–	–	–	+	–
Schroederia setigera (Schrod.) Lemm.	–	–	–	+	–	–	+	+	–	+	+	+	+	+	+	+	–	–	–	+	–	–	+	+	+	–
Kirchneriella intermedia Korsch.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
Kirchneriella irregularis (Smith) Korsch.	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chlorella vulgaris Beijer.	–	–	–	–	+	+	+	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–	–	+
Tetradesmus wisconsiensis G.M. Smith	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Oocystis marssonii Lemm.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–
Oocystis borgei Snow.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oocystis ovale Korsch.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Scenedesmus quadricauda (Turb.) Breb.	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Geminellopsis fragilis Korsch.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
Cylindrocapsa conferta W. West	–	+	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+
Cladophora globulina Kutz.	+	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyanophyta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aphanizomenon flos-aquae (L.) Ralfs.	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lingbya hieronymusii Lemm.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lingbya aestuarii (Mert.) Liebm.	+	–	–	–	–	–	–	+	+	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–
Lingbya limnetica Lemm.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	–	–	–	–	–	+	+
Lingbya kutzingii (Kutz.) Schmidle	–	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Nodularia spumigena f. *spumigena* Mert.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Oscillatoria chlorina (Kutz.) Gom.	–	–	–	–	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oscillatoria amphibia Ag.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Oscillatoria limosa Ag.	–	–	–	–	–	+	–	+	+	–	+	–	–	–	+	–	–	–	–	–	–	+	–	–	+	–
Oscillatoria agardhii f. *aequicrassa* Elenk.	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Synechocystis salina Wisl.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Synechococcus elongatus Nag.	+	–	–	+	+	+	+	+	+	–	+	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–
Cryptophyta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cryptomonas sp.	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Dinophyta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gimnodinius albulus Lind.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Gimnodinius cnecoides Harris	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Xanthophyta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tribonema viride Pasch.	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–
All species...	13	10	7	11	13	14	11	25	9	14	17	7	14	8	10	13	7	10	16	6	5	8	6	8	17	12

Note. "+" — species is found out; "–" — species is not found out.

Appendix 8. **The number of algae species from different taxonomic group**

Name of the algae taxonomic units	Siverga	Okunevskoye	Cherdynskoye	N.-Georgievskoye	B. Medvezhye	M. Medvezhye	Filatovo	Nevidim	Umreshevo	B. Kureynoye	Trebushinoye	Sobachye	Vishnyakovskoye	Aktoban	Voskresenskoye	Gashkovo	Setovo	Borki	Shamelya	Lavrusheno	Aslykul	Oktyabrskoye	Soleniy Kulat	Tauzatkul	Ulzhay	Ebeyty
Bacyllariophyta	4/31	3/30	2/29	3/27	4/31	4/29	2/18	6/24	2/22	5/36	3/18	2/29	5/36	3/38	3/38	3/23	2/29	5/31	8/50	4/67	3/60	3/38	2/40	3/38	4/24	5/42
Chlorophyta	6/46	5/50	4/57	6/55	5/38	5/36	6/55	12/48	3/33	7/50	8/47	3/43	7/50	4/50	4/50	8/62	3/43	4/25	7/44	2/33	2/40	3/38	3/60	5/63	8/47	5/42
volvoxes	5/38	3/30	3/43	4/36	4/31	4/29	4/36	8/32	3/33	5/36	6/35	2/29	5/36	3/38	3/38	6/46	3/43	4/25	5/31	1/17	2/40	3/38	2/40	2/25	4/24	3/25
chlorococcales	0/0	0/0	1/14	2/18	1/8	1/7	2/18	2/8	0/0	2/14	2/12	1/14	2/14	1/13	1/13	1/8	0/0	0/0	2/13	1/17	0/0	0/0	1/20	2/25	4/24	1/8
filamentous	1/8	2/20	0/0	0/0	0/0	0/0	0/0	2/8	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/8	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/13	0/0	1/8
Cyanophyta	3/23	2/20	1/14	2/18	4/31	5/36	3/27	6/24	4/44	1/7	5/29	2/29	2/14	1/13	1/13	2/15	1/14	1/6	1/6	0/0	0/0	1/13	0/0	0/0	4/24	2/17
Cryptophyta	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/4	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/14	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Dinophyta	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/6	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/6	0/0
Xantophyta	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/7	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/13	0/0	0/0	0/0	0/0
The total number of species...	13	10	7	11	13	14	11	25	9	14	17	7	14	8	8	13	7	10	16	6	5	8	5	8	17	12

Note. Above line — number of species, below line — percentage ratio.

Appendix 9. **Phytoplankton communities structure in lakes during vegetative season**

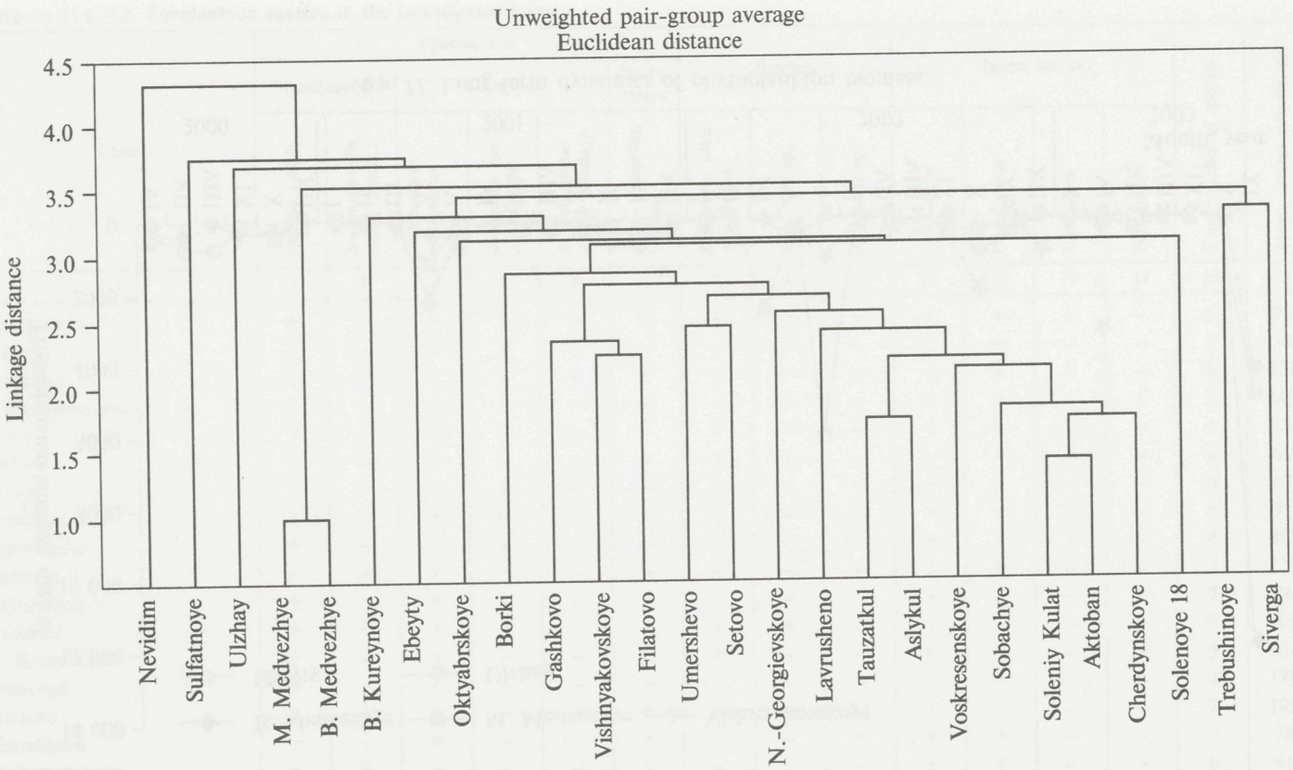
Lake	Month, year	Dominant and subdominant	Number of species	Biomass, mg/l min–max / average	Volume of cell, μm³	The proportion of biomass of different groups of algae, %						
						volvoxes	*chlorococcales*	*filamentous*	Cyanophyta	Dinophyta	Bacyllariophyta	Xantophyta
1	2	3	4	5	6	7	8	9	10	11	12	13
B. Medvezhye	VI–VII 1995	*Oscillatoria* sp., *Nitzschia angustata*	8	0.15–1.18 / 0.67	119	4	0	0	28	0	68	0
	V–X 2000	*Dunaliella salina, D. viridis*	11	0.09–7.20 / 1.33	275	77	1	0	1	0	21	0
	IV–X 2001	*Dunaliella salina, Lyngbya limnetica*	7	0.02–2.14 / 0.50	60	53	3	0	14	0	30	0
	IV–X 2002	*Dunaliella salina, Nitzschia angustata*	6	0.03–1.12 / 0.74	135	35	0	0	16	0	49	0
	VI–X 2003	*Dunaliella salina, Nitzschia angustata*	4	0.03–0.38 / 0.24	134	50	0	0	2	0	48	0
M. Medvezhye	V–X 2000	*Dunaliella salina, D. viridis*	10	0.19–8.12 / 1.64	314	80	1	0	1	0	18	0
	IV–X 2001	*Dunaliella salina, Lyngbya limnetica*	7	0.03–1.28 / 0.35	40	67	7	0	13	0	13	0
	IV–X 2002	*Dunaliella salina, D. viridis*	7	0.03–6.22 / 0.95	148	49	0	0	19	0	32	0
	VI–X 2003	*Dunaliella salina*	4	0.02–0.11 / 0.05	124	21	0	0	9	0	70	0
Nevidim	VII–VIII 1995	*Dunaliella salina, Spermatozopsis exsultans*	15	0.17–2.93 / 1.55	109	28	21	7	14	0	30	0
	VII–VIII 2000	*Lyngbya aestuarii, Dunaliella salina, D. viridis*	13	0.77–3.51 / 2.14	412	17	0,2	0	75	0,8	7	0
	IV–X 2001	*Ankyra judayi, Lyngbya limnetica*	11	0.18–2.81 / 1.32	110	39	31	0	20	0	10	0
	IV–X 2002	*Chlamidomonas Reinhardii, Oscilatoria limosa, Dunaliella salina*	12	0.003–13.23 / 2.16	860	68	6	0	14	0	12	0
	VI–X 2003	*Schroederia setigera*	5	0.02–0.45 / 0.36	66	22	72	0	0	0	6	0
Vishnyakovskoye	IV–X 2001	*Dunaliella salina, D. viridis*	9	0.04–0.75 / 0.33	118	59	24	0	4	0	13	0
	VII, IX 2000	*Nitzschia angustata, Dunaliella salina, D. viridis*	8	0.353–0.612 / 0.48	266	55.5	0.1	0	0.4	0	44	0
Filatovo	VII–VIII 2000	*Dunaliella salina, D. viridis*	11	0.609–1.204 / 0.91	109	74	0.3	0	7.7	0	18	0
	IV–X 2001	*Dunaliella salina, D. viridis*	7	0.35–0.77 / 0.527	260	82	0	0	6	0	12	0
Trebushinoye	VIII 1995	*Nitzschia longissima, Dunaliella salina*	7	11.38	323	44	5	0	0	1	50	0
	VII–VIII 2000	*Dunaliella salina, Lyngbya aestuarii*	7	0.118–0.124 / 0.121	360	49	2	0	29	0	20	0
	IV–IX 2001	*Dunaliella salina, D. viridis*	10	0.012–2.550 / 1.215	169	78	0	0	16	0	6	0
Aktoban	VII–VIII 2000	*Nitzschia angustata, Dunaliella salina, D. viridis*	5	0.016–0.104 / 0.06	211	48	0	0	3	0	49	0
	V–VIII 2001	*Nitzschia angustata, Ankyra judayi*	6	0.031–0.069 / 0.045	93	17	26	0	17	0	40	0
Shamelya	VII 1995	*Korschikoviella gracilipes*	7	1.15	336	5	72	0	0	0	23	0
	VII, IX 2000	*Nitzschia longissima, Dunaliella salina, D. viridis*	7	0.449–1.010 / 0.73	115	34	5	0	4	0	57	0
	IV–IX 2001	*Ankyra judayi*	8	0.018–1.259 / 0.460	75	9	87	0	2	0	2	0
Cherdynskoye	VIII 2000	*Nitzschia angustata*	5	0.22	244	32	0	0	1	0	67	0

Appendix 9 (continued)

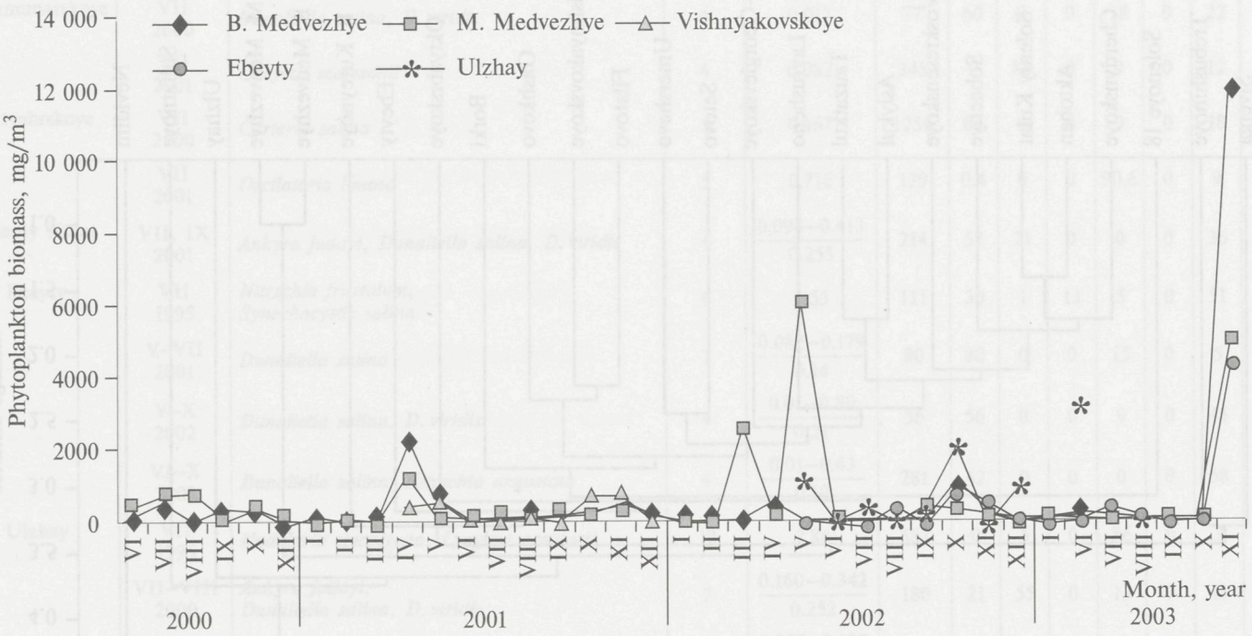
1	2	3	4	5	6	7	8	9	10	11	12	13
Cherdynskoye	IV–IX 2001	*Kirchneriella irregularis, Nitzschia angustata*	5	0.067–0.302 / 0.217	41	13	46	0	19	0	22	0
B. Kureynoye	VII 1995	*Dunaliella salina*	5	0.57	353	69	3	0	0	0	38	0
	VII–VIII 2000	*Nitzschia angustata, Dunaliella salina*	4	0.037–0.090 / 0.063	263	42	0	0	0	0	58	0
	IV–VIII 2001	*Dunaliella salina, D. viridis*	7	0.145–0.534 / 0.27	77	79	2	0	14	0	4	0
Voskresenskoye	VII–VIII 2000	*Lyngbya aestuarii*	8	0.131–0.195 / 0.16	188	21	22	0	36	0	21	0
	VI, IX 2001	*Oscillatoria limosa*	5	0.038–0.534 / 0.287	220	0	5	0	93	0	2	0
N.-Georgiev-skoye	VII 2000	*Amphora coffeaeformis*	4	0.01	73	10	0	0	11	0	79	0
	IV–IX 2001	*Chlamidomonas Reinhardii*	9	0.003–12.26 / 3.20	521	93	0	0	3	0	4	1
Gashkovo	VII, IX 2000	*Dunaliella salina*	5	0.114–0.438 / 0.28	278	59	0	0	4	0	37	0
	VII–X 2001	*Ankyra judayi, Dunaliella*	9	0.895–2.56 / 1.379	244	17	72	1	1	0	9	0
Borki	VII, IX 2000	*Nitzschia angustata, N. obfusa* var. *nana*	5	0.44–0.78 / 0.61	82	8	0	0	6	0	86	0
	VII, IX 2001	*Nitzschia thermalis*	5	0.015–0.038 / 0.026	283	29	3	0	0	0	68	0
Setovo	VII 2000	*Dunaliella salina*	3	0.042	296	77	0	0	0	0	23	0
	VII, IX 2001	*Spermatozopsis exultans*	4	0.121–0.160 / 0.141	57	66	0	0	22	0	12	0
Sobachye	VII–VIII 2000	*Dunaliella salina, Nitzschia angustata*	6	0.254–0.283 / 0.269	213	62	0	0	2	0	36	0
Sobachye	VI 2001	*Dunaliella salina, D. viridis*	3	0.067	358	89	0	0	9	0	2	0
Lake N 1	VII 2000	*Dunaliella salina*	5	0.056	146	72	0	0	10	0	18	0
Umreshevo	VIII 2000	*Lyngbya aestuarii, Dunaliella salina, Amphora coffeaeformis*	6	0.011–0.135 / 0.073	124	30	0	0	46	0	24	0
	VI, X 2001	*Dunaliella salina, D. viridis*	6	0.115–1.038 / 0.576	255	83	0	0	3	0	14	0
Shashmura	VIII 2000	*Dunaliella salina, D. viridis*	5	0.12	137	96	0	0	1	0	3	0
Kurtamyshskoye	VII 2001	*Nitzschia angustata*	1	0.011	458	0	0	0	0	0	100	0
Aslykul	VII, IX 2001	*Amphora coffeaeformis, Nitzschia longissima*	4	0.008–0.041 / 0.025	255	3	0	0	0	0	97	0
Tibizkol	VII, IX 2001	*Ankyra judayi, Spermatozopsis exsultans*	5	0.013–0.029 / 0.021	127	31	33	0	13	0	23	0
Lavrusheno	VII, IX 2001	*Ankyra judayi, Amphora coffeaeformis*	5	0.025–0.031 / 0.028	194	0	42	0	0	0	58	0
Solenoye 18	VII 1995	*Cladophora globulina, Lyngbya kutzingii*	7	3.49	89	0	0	95	1	0	4	0
	VII 2000	*Nitzschia angustata, Amphora coffeaeformis*	4	0.116	81	25	0	0	1	0	74	0
	V 2001	*Dunaliella salina, D. viridis*	4	0.022	158	61	0	0	23	0	16	
Siverga	VII 1995	*Cladophora globulina*	8	116.7	64 214	0	0	99	0	0	1	
	VII 2000	*Lyngbya aestuarii*	5	0.075	211	32	0	0	68	0	0	
	IV–V 2001	*Chlamidomonas Reinhardii*	6	0.157–1.120 / 0.494	266	88	0	0	11	0	1	
Tauzatkul	VII 2000	*Dunaliella salina, D. viridis*	3	0.069	246	70	0	0	0	0	30	0

Appendix 9 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13
Tauzatkul	VII 2001	*Geminellopsis fragilis*	3	1.55	48	0	7	83	0	0	10	0
Kommunarskoye	VII 2000	*Dunaliella salina, D. viridis*	4	0.017	77	60	0	0	18	0	22	0
	VII 2001	*Oocystis marssonii*	4	0.082	345	0	88	0	0	0	12	0
Oktyabrskoye	VII 2000	*Carteria salina*	5	0.167	1256	64	0	0	0	0	18	18
	VII 2001	*Oscilatoria limosa*	5	0.716	139	0.4	0	0	90.6	0	9	0
Soleniy Kulat	VII, IX 2001	*Ankyra judayi, Dunaliella salina, D. viridis*	4	0.098–0.413 / 0.255	214	53	21	0	0	0	26	0
Ebeyty	VII 1995	*Nitzschia frustulum, Synechocystis salina*	6	1.55	111	30	1	13	5	0	51	0
	V–VII 2001	*Dunaliella salina*	7	0.082–0.179 / 0.14	80	80	0	0	15	0	5	0
	V–X 2002	*Dunaliella salina, D. viridis*	4	0.01–0.80 / 0.21	56	56	0	0	9	0	45	0
	VI–X 2003	*Dunaliella salina, Nitzschia angustata*	4	0.01–0.43 / 0.10	281	42	0	0	0	0	58	0
Ulzhay	VII 1995	*Nodularia spumigena, Lyngbya aestuarii*	10	7.84	562	0	5	0	86	0	3	0
	VII–VIII 2000	*Ankyra judayi, Dunaliella salina, D. viridis*	7	0.160–0.342 / 0.252	180	21	55	0	13	0	11	0
	V, VIII 2001	*Lyngbya limnetica*	5	0.087–0.097 / 0.092	98	58	12	0	30	0	0	0
	V–X 2002	*Oscilatoria limosa, Ankyra judayi*	7	0.04–1.95 / 0.64	355	21	40.8	0	38	0	0.2	0
	VI–X 2003	*Oscillatoria limosa, Dunaliella salina*	5	0.02–3.29 / 1.13	519	14	2	0	45	0	39	



App. 10. Dendrogram of associations on species structure of phytoplankton in 26 investigated lakes.



App. 11. Long-term dynamics of phytoplankton biomass.

Appendix 12. **Zooplankton species in the investigated lakes**

Lake	Crustaceans						Rotifers			Insect larvae				Total number of species	Mean annual salinity, g/l
	Branchiopods		Copepods			Cladocerans									
	Artemia Leach.	*Branchinectella media* (Schm.)	*Cletocamptus retrogressus* Schm.	*Diaptomus cyaneus* Kiefer	*Arctodiaptomus salinus* (Daday)	*Moina mongolica* (Straus)	*Brachionus plicatilis* Muller	*Hexarthra* sp.	*Epiphanes* sp.	Ephydridae	Chiromidae	Plecoptera	Nematodes		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lavrusheno	+	–	+	–	–	+	+	+	+	+	+	–	–	8	95
Aslykul	+	–	+	–	–	–	–	–	–	–	+	–	–	3	52
Shamelya	+	–	+	–	–	+	+	–	–	+	+	–	–	6	117
Vishnyakovskoye	+	–	+	–	–	–	–	–	–	+	+	–	+	5	149
Tibizkol	+	–	+	–	–	–	+	–	–	+	+	–	–	5	72
Setovo	+	–	+	–	–	+	+	+	–	–	+	–	–	6	60
Borki	+	–	+	–	+	–	+	–	–	+	+	–	–	6	57
Gashkovo	+	–	+	–	–	+	+	–	–	+	+	–	–	6	91
Svetlenkoye	+	–	–	–	–	–	+	–	–	+	+	–	–	4	47*
Aktoban	+	+	+	–	–	–	–	–	–	+	+	–	–	5	125
Trebushinoye	+	+	+	–	–	+	+	–	–	+	+	–	–	7	74
Nevidim	+	–	+	+	–	+	+	+	–	+	+	–	+	9	105
B. Kureynoye	+	–	+	–	–	–	+	–	–	+	+	–	–	5	104
Sobachye	+	–	–	–	–	–	–	–	–	+	–	–	–	2	179
Filatovo	+	+	+	–	–	+	+	–	–	+	+	–	–	7	105
Umreshevo	+	–	+	–	–	+	+	–	+	+	+	–	–	7	78
Voskresenskoye	+	+	+	–	–	+	–	–	–	+	+	–	–	6	61
N.-Georgievskoye	+	+	+	–	–	+	+	–	–	+	+		–	7	80
B. Medvezhye	+	–	+	–	–	–	–	–	–	+	+	–	+	5	176
M. Medvezhye	+	–	+	–	–	–	–	–	–	+	+	–	+	5	176

Appendix 12 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cherdynskoye	+	–	+	–	–	–	–	–	–	+	–	–	–	3	151
Shashmura	+	–	–	–	–	–	–	–	–	–	–	–	–	1	226
Kurtamyshskoye	+	–	–	–	–	+	+	–	–	+	–		–	4	57
Lake N 1	+	–	–	–	–	–	–	–	–	–	–	–	–	1	222
Ulzhay	+	–	+	–	–	+	–	+	–	+	+	–	–	6	77
Ebeyty	+	–	+	–	–	–	–	–	–	+	+		+	5	206
Solenoye 18	+	–	+	–	–	–	–	–	–	+	–	–	+	4	83
Siverga	+	+	+	–	–	+	–	–	–	+	+	+	–	7	59
Okunevoye	+	–	+	–	–	–	–	–	–	–	–	–	–	2	95*
Sosnovskoye	+	–	+	–	–	–	–	–		+	–	–	+	4	80
Bersenevskoye	+	–	+	–	–	–	–	–	–	+	+	–	–	4	97
Soleniy Kulat	+	–	+	–	–	–	+	–	–	+	+	–	–	5	105
Oktyabrskoye	+	–	+	–	–	+	+	–	–	–	+	–	–	5	54
Kommunarskoye	+	–	+	–	–	+	+	–	–	–	–	–	–	4	57
Tauzatkul	+	+	+	–	–	+	+	–	–	–	+	–	–	6	41
B. Yarovoye	+	–	–	–	–	–	–	–	–	–	–	–	–	1	172*
Kulundinskoye	+	–	+	–	–	–	+	–	–	–	–	–	–	3	92*
Malinovoye	+	–	–	–	–	–	–	–	–	–	–	–	–	1	255*
Tanatar 1	+	–	–	–	–	–	–	–	–	–	–	–	–	1	110*
Gornastalevo	+	–	–	–	–	–	–	–	–	–	–	–	–	1	250*
Kurichye	+	–	+	–	–	–	–	–	–	–	–	–	–	2	140*
Chekurtuz	+	–	–	–	–	–	–	–	–	–	–	–	–	1	240*
Krivaya Puchina	+	–	+	–	–	–	–	–	–	–	–	–	–	2	140*
Cheder	+	–	–	–	–	–	+	–	–	–	–		–	2	119*
Pervomayskoye	+	–	–	–	–	–	–		–	+	–	–	–	2	76*
Tus	+	–	–	–	–	–	–	–	–	+	–	–	–	2	131*
Occurrence of species, %	100	15	72	2	2	35	44	9	4	63	57	2	15		

Note. * 1–2 times study.

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Appendix 13. **Morphometric parameters of Artemia cysts and nauplii in populations of some lakes of Western Siberia**

Lake	The diameter of the cysts, μm						The diameter of decapsulated cysts, μm						The thickness of the chorion, μm	The length of the hatched nauplii, μm					
	$M \pm m$	min	max	C_v	δ	n	$M \pm m$	min	max	C_v	δ	n		$M \pm m$	min	max	C_v	δ	n
B. Medvezhye	257.45 ± 0.97	240	300	5.50	14.10	210	242.26 ± 1.37	216	288	5.66	13.72	100	7.60	469.4 ± 5.7	384	520	6.65	31.19	30
Ebeyty	256.80 ± 1.73	204	300	6.73	17.29	200	248.92 ± 1.44	192	290	5.79	14.39	200	3.94	467.8 ± 3.3	396	506	4.91	22.98	50
Sobachye	270.08 ± 2.16	224	352	7.99	21.61	100	245.04 ± 1.61	192	300	6.57	16.11	100	12.52	456.2 ± 3.3	440	484	3.94	17.96	30
Umreshevo	260.88 ± 1.85	228	372	7.08	18.50	100	251.68 ± 1.36	220	304	5.41	13.62	100	4.60	463.8 ± 4.6	418	492	4.48	20.79	20
Trebushinoye	278.40 ± 1.54	240	312	5.51	15.35	100	257.40 ± 1.53	216	288	5.94	15.29	100	10.50	489.6 ± 4.1	440	550	4.61	22.59	30
N.-Georgievskoye	272.32 ± 1.89	224	320	6.93	18.89	100	252.16 ± 1.46	208	288	5.78	14.58	100	10.08	477.3 ± 4.1	440	507	3.85	18.36	20
B. Kureynoye	260.12 ± 1.14	224	320	6.37	16.57	210	237.64 ± 1.14	204	300	6.97	16.57	210	11.24	486.1 ± 3.5	440	515	3.97	19.31	30
Aktoban	289.12 ± 1.75	256	336	6.05	17.51	100	264.64 ± 1.19	240	288	4.50	11.91	100	12.24	502.1 ± 4.7	440	550	5.11	25.64	30
Nevidim	266.45 ± 0.98	240	300	5.19	13.82	200	249.34 ± 0.77	224	288	4.35	10.87	200	8.56	475.4 ± 3.4	418	504	4.44	21.11	40
Filatovo	272.32 ± 1.78	224	320	6.52	17.76	100	254.04 ± 1.96	204	300	7.71	19.60	100	9.14	470.6 ± 4.2	396	505	4.86	22.85	30
Vishnyakovskoye	264.80 ± 1.57	224	304	5.92	15.65	100	251.88 ± 2.32	210	290	9.19	23.17	100	6.46	—	—	—	—	—	—
Ulzhay	240.90 ± 1.19	205	290	4.94	11.90	100	218.10 ± 1.09	190	280	4.99	10.9	100	11.4	432.3 ± 3.7	380	450	3.82	16.51	20

Appendix 14. **Results of morphological researches of Artemia populations from 1995 to 2004**

Index	Year								
	1995	1996	1997	2000	2001	2002	2002*	2003	2004
1	2	3	4	5	6	7	8	9	10
n	7	8	11	22	23	29	13	11	14
Σ_i, g/l	52–204 / 110.4 ± 19.9	45–233 / 113.0 ± 21.4	66–263 / 118.6 ± 16.8	43–242 / 134.3 ± 12.8	40–292 / 101.7 ± 12.8	28–275 / 102.6 ± 11.8	28–210 / 96.9 ± 16.4	53–156 / 96.3 ± 12.5	51–264 / 127.5 ± 16.4
tl, mm	6.3–11.7 / 8.47 ± 0.76	7.6–10.9 / 8.88 ± 0.41	6.3–10.3 / 8.71 ± 0.34	8.0–10.8 / 9.18 ± 0.18	7.38–12.28 / 9.85 ± 0.23	7.25–10.98 / 8.89 ± 0.16	8.62–10.04 / 9.44 ± 0.04	6.81–10.58 / 9.33 ± 0.05	8.52–11.26 / 9.69 ± 0.06

Appendix 14 (continued)

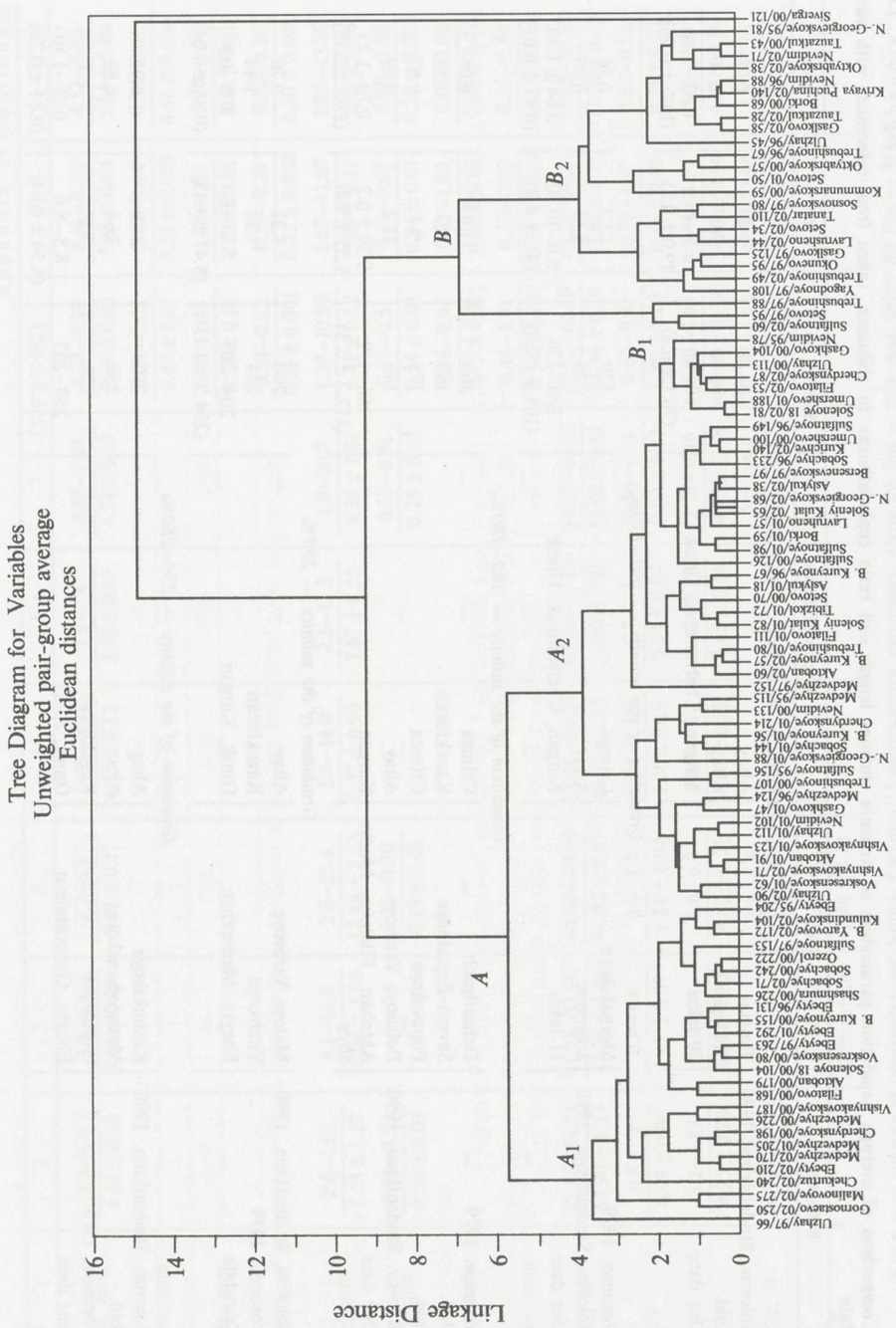
1	2	3	4	5	6	7	8	9	10
al, mm	2.7–6.4 / 4.36 ± 0.48	3.2–4.6 / 4.18 ± 0.16	2.7–5.1 / 3.91 ± 0.17	3.89–5.9 / 4.55 ± 0.12	3.9–7.4 / 5.36 ± 0.17	3.65–7.04 / 4.74 ± 0.13	4.08–5.99 / 5.19 ± 0.06	3.14–6.22 / 5.05 ± 0.04	4.53–6.85 / 5.64 ± 0.04
aw, mm	—	—	—	—	—	—	0.29–0.68 / 0.47 ± 0.01	0.47–0.64 / 0.55 ± 0.003	0.33–0.61 / 0.48 ± 0.004
de, mm	—	—	—	—	—	—	0.86–1.46 / 1.25 ± 0.01	1.05–1.54 / 1.30 ± 0.01	0.96–1.53 / 1.28 ± 0.01
ed, mm	—	—	—	—	—	—	0.10–0.22 / 0.16 ± 0.001	0.19–0.29 / 0.23 ± 0.002	0.16–0.26 / 0.20 ± 0.001
sf, mm	2.6–13.1 / 7.53 ± 1.27	4.1–14.8 / 10.06 ± 1.20	2.6–21.4 / 12.48 ± 2.03	1.5–14.0 / 6.57 ± 0.90	2.1–13.3 / 7.67 ± 0.55	1.0–20.7 / 9.30 ± 1.01	1.29–10.60 / 4.41 ± 0.12	2.60–11.07 / 5.89 ± 0.17	1.85–13.60 / 5.62 ± 0.16
fl, mm	0.08–0.32 / 0.20 ± 0.03	—	0.18–0.20 / 0.19 ± 0.01	—	—	0.13–0.51 / 0.26 ± 0.02	0.13–0.51 / 0.24 ± 0.01	0.21–0.69 / 0.34 ± 0.01	0.08–0.35 / 0.20 ± 0.003
la, mm	—	—	—	—	—	—	0.56–0.96 / 0.79 ± 0.01	0.62–1.00 / 0.85 ± 0.01	0.66–0.90 / 0.80 ± 0.01
hw, mm	—	—	—	—	—	—	0.46–1.01 / 0.54 ± 0.01	0.50–0.82 / 0.65 ± 0.004	0.36–0.64 / 0.53 ± 0.004
ra, %	42.86–54.71 / 50.90 ± 1.53	41.28–51.90 / 47.26 ± 1.41	40.00–49.00 / 44.82 ± 0.87	35.44–60.25 / 49.05 ± 1.05	40.09–59.18 / 52.80 ± 0.95	44.67–64.12 / 53.02 ± 0.81	47.92–61.10 / 54.30 ± 0.18	45.28–58.27 / 52.95 ± 0.30	53.05–62.17 / 57.98 ± 0.19
c/a	0.8–1.3 / 0.99 ± 0.06	0.9–1.4 / 1.12 ± 0.07	1.0–1.5 / 1.24 ± 0.04	0.64–1.58 / 1.05 ± 0.19	0.7–1.5 / 0.93 ± 0.04	0.56–1.14 / 0.90 ± 0.03	0.63–0.91 / 0.80 ± 0.03	0.70–1.17 / 0.86 ± 0.06	0.65–0.88 / 0.74 ± 0.03
cl	3.2–5.87 / 4.25 ± 0.39	3.8–6.4 / 4.69 ± 0.30	3.6–6.0 / 4.81 ± 0.21	3.18–6.47 / 4.68 ± 0.15	3.42–6.77 / 4.65 ± 0.14	3.16–4.96 / 4.15 ± 0.08	3.80–4.66 / 4.15 ± 0.09	3.56–4.55 / 4.04 ± 0.14	3.65–4.41 / 4.03 ± 0.10
f/a, %	2.1–7.1 / 4.9 ± 0.6	—	5.0–6.6 / 5.8 ± 0.3	—	—	2.3–11.4 / 5.6 ± 0.5	2.28–6.99 / 4.21 ± 0.63	4.24–22.00 / 8.91 ± 2.00	1.67–7.20 / 3.85 ± 0.66
fw	—	0.10–1.40 / 0.66 ± 0.14	0.30–1.20 / 0.88 ± 0.10	—	—	—	—	—	—

Note. *n* — quantity of investigated populations; * studied 13 morphometric parameters. Above the line — min–max, below the line — $M \pm m$.

Appendix 15

Comparison of average population parameters of Artemia shrimps length and ratio cephalothorax to abdomen, taken from references with our data

Reference	Lake	Region of Russia	Salinity, ‰	*tl*	*c/a*
		Gradation of the salinity — 60–80‰			
Solovov, Studenikina, 1990	Tanatar	Altay	60–80	9.83	0.78
Ibid.	Shekulduk	Altay	60–80	7.07	0.90
Our date	20 lakes	Kurgan, Chelyaninsk, Omsk	60–80 (70.1 ± 0.4)	6.3–10.9 (9.0 ± 0.2)	0.83–1.40 (1.06 ± 0.04)
		Gradation of the salinity — 100–130‰			
Voronov, 1979	Moinakskoye	Crimea	129	12.3	0.76
Solovov, Studenikina, 1990	Solenoye	Altay	130	8.51	0.90
Our date	11 lakes	Kurgan, Chelyaninsk, Omsk	100–126 (108.5 ± 2.2)	8.0–10.70 (9.2 ± 0.3)	0.64 ± 1.30 (0.97 ± 0.05)
		Gradation of the salinity — 160–180‰			
Voronov, 1979	Dzharilgach	Crimea	160	11.03	0.68
Ibid.	Severo-Zapadnoye	Kazakhstan	169	8.7	1.18
Ibid.	Popovskoye	Crimea	173	9.4	0.62
Solovov, Studenikina, 1990	Bolshoye Yarovoye	Altay	180	11.2	0.69
Our date	Aktoban, Filatovo, Medvezhye	Kurgan	168–179 (172.2 ± 3.5)	9.39 ± 0.2 9.35 ± 9.41	0.70–1.23 (1.05 ± 0.18)
		Gradation of the salinity — 200‰			
Solovov, Studenikina, 1990	Maloye Yarovoye	Altay	200	9.21	0.76
Voronov, 1979	Yuzhnoye	Kazakhstan	204	7.32	1.44
Our date	Ebeyty, Medvezhye	Omsk, Kurgan	204–205 (204.5 ± 1.13)	7.3–9.6 (8.43 ± 1.13)	0.8–0.9 (0.84 ± 0.04)
		Gradation of the salinity — 250–260‰			
Solovov, Studenikina, 1990	Kushukskoye	Altay	250	8.19	0.95
Ibid.	Mormyshanskoye	Altay	250	7.64	0.82
Voronov, 1979	Gorbatoye	Kazakhstan	259	7.0	1.5
Our date	Ebeyty, Gornostalevo	Omsk, Altay	250–263 (256.5 ± 6.5)	8.5–8.6 (8.54 ± 0.04)	0.58–1.10 (0.84 ± 0.26)



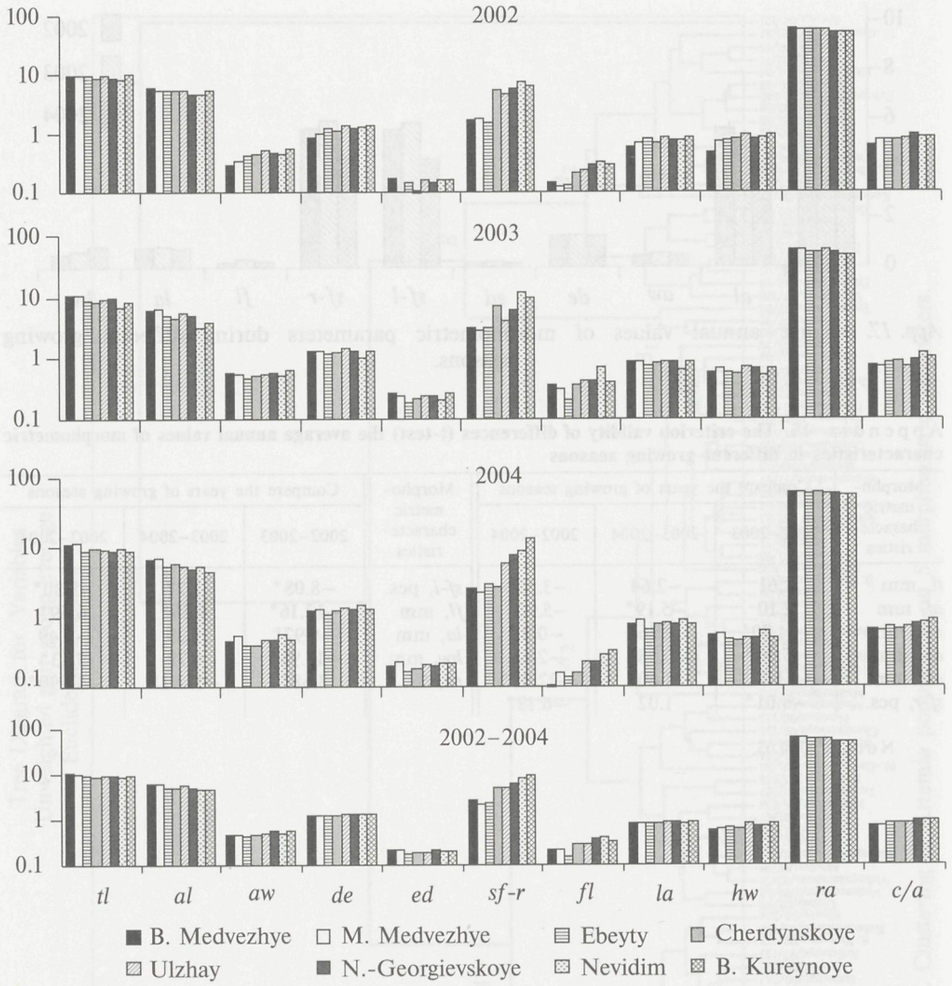
App. 16. Clustering of Artemia populations on 5 morphometric parameters.

App. 17. Average annual values of morphometric parameters during different growing seasons.

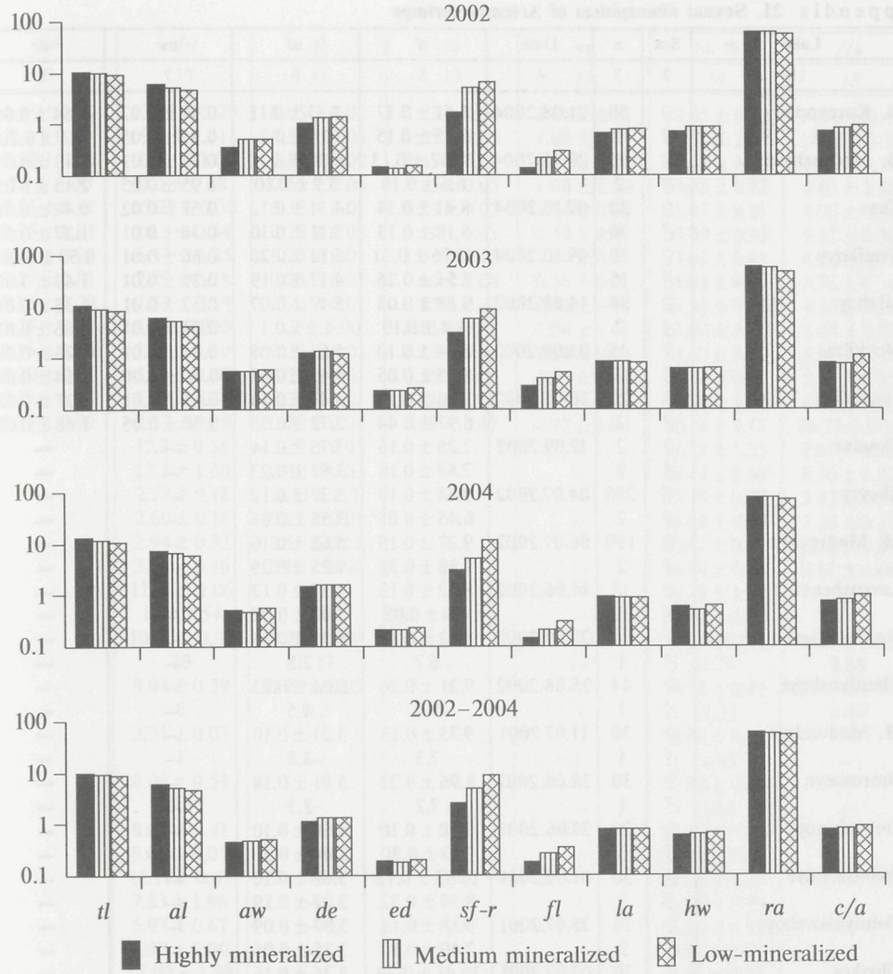
Appendix 18. **The criterion validity of differences (t-test) the average annual values of morphometric characteristics in different growing seasons**

Morphometric characteristics	Compare the years of growing seasons			Morphometric characteristics	Compare the years of growing seasons		
	2002–2003	2003–2004	2002–2004		2002–2003	2003–2004	2002–2004
tl, mm	1.61	−2.64	−3.50*	*sf-l*, pcs.	−8.08*	1.27	−5.80*
al, mm	2.10	−5.19*	−5.90*	*fl*, mm	−12.16*	4.58*	6.59*
aw, mm	−11.70*	2.16	−0.88	*la*, mm	−6.97*	1.39	−0.49
de, mm	−5.00*	0.58	−2.61	*hw*, mm	−15.93*	0.72	3.53*
ed, mm	−33.41*	1.60	−22.08*	*ra*, %	3.68*	−11.91*	−13.90*
sf-r, pcs.	−8.01*	1.02	−6.18*				

Note. * $p < 0.05$.



App. 19. Mean values of morphometric parameters of Artemia from different Siberian populations in seasons of 2002, 2003, 2004.



App. 20. Average values of morphometric parameters of Artemia grouped by salinity during vegetative seasons 2002, 2003, 2004 and as whole for 2002–2004.

Appendix 21. **Sexual dimorphism of Artemia shrimps**

Lake	Sex	*n*	Date	*tl*	*al*	*aw*	*de*	*ed*	*sf-r*	*fl*	*la*	*hw*	*ra*, %	*f/a*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B. Kureynoye	♀	50	21.08.2004	8.51 ± 0.17	4.53 ± 0.11	0.94 ± 0.02	2.54 ± 0.06	0.43 ± 0.01	13.68 ± 0.29	0.65 ± 0.02	1.53 ± 0.04	1.01 ± 0.02	53.05 ± 0.62	14.76 ± 0.44
	♂	2		6.25 ± 0.15	3.1 ± 0.2	0.85 ± 0.05	2.1 ± 0.20	0.4 ± 0.00	9.5 ± 2.51	0.55 ± 0.05	1.35 ± 0.05	1.00 ± 0.00	49.55 ± 2.02	17.92 ± 2.78
B. Medvezhye	♀	50	20.08.2004	10.07 ± 0.13	6.36 ± 0.11	0.70 ± 0.01	2.19 ± 0.04	0.32 ± 0.01	2.31 ± 0.17	0.20 ± 0.02	1.45 ± 0.03	0.87 ± 0.02	63.07 ± 0.52	3.09 ± 0.24
	♂	2		6.6 ± 0.10	3.9 ± 0.10	0.95 ± 0.05	2.15 ± 0.05	0.4 ± 0.00	2.5 ± 0.50	0.35 ± 0.05	1.15 ± 0.05	1.00 ± 0.00	59.08 ± 0.62	9.01 ± 1.52
Tus	♀	30	07.10.2004	8.41 ± 0.14	4.31 ± 0.12	0.57 ± 0.02	0.48 ± 0.01	0.26 ± 0.01	15.23 ± 0.36	0.39 ± 0.01	0.93 ± 0.02	1.44 ± 0.03	51.07 ± 0.81	9.05 ± 0.24
	♂	30		6.18 ± 0.13	3.11 ± 0.10	0.36 ± 0.01	1.27 ± 0.03	0.25 ± 0.01	10.5 ± 0.44	0.29 ± 0.03	0.79 ± 0.03	0.50 ± 0.01	50.09 ± 0.93	9.32 ± 0.30
Svatikovo	♀	30	09.10.2004	10.76 ± 0.31	6.14 ± 0.20	0.60 ± 0.01	0.50 ± 0.001	0.25 ± 0.01	6.47 ± 0.35	0.28 ± 0.01	1.00 ± 0.03	1.48 ± 0.04	57.03 ± 0.68	4.56 ± 0.20
	♂	15		7.54 ± 0.26	4.17 ± 0.19	0.39 ± 0.01	1.49 ± 0.06	0.27 ± 0.01	7.29 ± 0.78	0.24 ± 0.02	0.96 ± 0.05	0.56 ± 0.02	55.02 ± 0.97	5.76 ± 0.38
Ulzhay	♀	84	14.08.2002	9.88 ± 0.08	5.47 ± 0.07	0.52 ± 0.01	1.32 ± 0.01	0.16 ± 0.00	4.57 ± 0.19	0.23 ± 0.01	0.85 ± 0.02	0.92 ± 0.01	55.32 ± 0.40	4.35 ± 0.11
	♂	2		8.4 ± 0.10	4.5 ± 0.1	0.54 ± 0.01	1.86 ± 0.01	0.35 ± 0.01	5.5 ± 0.050	0.2 ± 0.00	0.85 ± 0.01	1.04 ± 0.01	53.67 ± 0.46	4.44 ± 0.10
Nevidim	♀	45	02.08.2002	8.64 ± 0.10	4.63 ± 0.08	0.44 ± 0.01	1.25 ± 0.03	0.16 ± 0.00	7.18 ± 0.30	0.32 ± 0.01	0.73 ± 0.02	0.86 ± 0.01	53.42 ± 0.50	6.92 ± 0.28
	♂	2		8.45 ± 0.05	4.45 ± 0.05	0.40 ± 0.00	1.64 ± 0.01	0.30 ± 0.01	7.50 ± 0.50	0.25 ± 0.01	0.55 ± 0.01	0.95 ± 0.05	52.37 ± 0.57	5.51 ± 0.05
Tauzatkul	♀	20	16.06.2002	9.06 ± 0.19	4.47 ± 0.16	0.62 ± 0.01	1.27 ± 0.02	0.17 ± 0.01	6.47 ± 0.38	0.36 ± 0.01	0.61 ± 0.02	0.83 ± 0.02	49.36 ± 1.02	8.17 ± 0.36
	♂	3		6.97 ± 0.44	2.72 ± 0.35	0.50 ± 0.05	1.48 ± 0.02	0.27 ± 0.02	8.33 ± 0.88	0.28 ± 0.04	0.98 ± 0.07	0.92 ± 0.04	39.18 ± 5.17	10.39 ± 0.90
Tanatar	♀	2	17.09.2002	7.25 ± 0.16	3.75 ± 0.14	—	—	—	17.3 ± 0.36	0.37 ± 0.03	—	—	51.72 ± 1.23	9.87 ± 0.34
	♂	8		7.83 ± 0.16	3.87 ± 0.23	—	—	—	13.3 ± 1.00	0.37 ± 0.03	—	—	49.43 ± 0.68	9.56 ± 0.52
Ebeyty	♀	393	04.07.2002	9.63 ± 0.10	5.37 ± 0.12	—	—	—	2.77 ± 0.16	0.13 ± 0.2	—	—	55.76 ± 0.82	2.42 ± 0.24
	♂	2		6.45 ± 0.05	3.55 ± 0.06	—	—	—	2.60 ± 0.18	0.12 ± 0.01	—	—	55.04 ± 0.65	3.38 ± 0.14
M. Medvezhye	♀	199	06.07.2002	9.27 ± 0.15	5.62 ± 0.16	—	—	—	2.94 ± 0.33	0.13 ± 0.02	—	—	60.41 ± 0.93	2.32 ± 0.36
	♂	2		7.85 ± 0.32	4.25 ± 0.29	—	—	—	3.00 ± 0.16	0.12 ± 0.00	—	—	54.14 ± 0.36	2.82 ± 0.60
Lavrusheno	♀	18	14.06.2002	8.62 ± 0.13	4.37 ± 0.12	—	—	—	17.42 ± 1.06		—	—	50.70 ± 1.12	
	♂	10		6.9 ± 0.05	3.03 ± 0.08	—	—	—	17 ± 0.54		—	—	43.91 ± 0.69	
N.-Georgievskoye	♀	90	22.07.2002	8.52 ± 0.12	4.35 ± 0.15	—	—	—	10.16 ± 0.33	0.28 ± 0.01	—	—	51.18 ± 0.46	6.44 ± 0.32
	♂	1		6.7	2.8	—	—	—	10	0.27	—	—	41.79	9.64
Cherdynskoye	♀	44	25.06.2002	9.21 ± 0.26	5.04 ± 0.25	—	—	—	8.04 ± 0.39	0.20 ± 0.02	—	—	54.72 ± 2.35	3.97 ± 0.54
	♂	1		8.6	4.5	—	—	—	8	0.2	—	—	52.33	4.44
M. Medvezhye	♀	30	11.07.2001	9.75 ± 0.13	5.21 ± 0.10	—	—	—	2.31 ± 0.02	—	—	—	53.44 ± 0.98	—
	♂	1		7.3	3.8	—	—	—	1	—	—	—	52.05	—
Umreshevo	♀	30	28.06.2001	8.96 ± 0.22	5.01 ± 0.18	—	—	—	8.08 ± 0.59	—	—	—	55.92 ± 0.59	—
	♂	1		7.2	3.3	—	—	—	6.5	—	—	—	45.83	—
Trebushinoye	♀	30	27.06.2001	8.50 ± 0.10	4.60 ± 0.10	—	—	—	8.00 ± 0.41	—	—	—	54.12 ± 0.56	—
	♂	3		7.10 ± 0.20	3.00 ± 0.30	—	—	—	9.00 ± 0.00	—	—	—	42.25 ± 0.65	—
Trebushinoye	♀	30	01.09.2001	10.92 ± 0.12	5.60 ± 0.10	—	—	—	11.11 ± 0.68	—	—	—	51.28 ± 0.23	—
	♂	2		8.53 ± 0.32	3.87 ± 0.19	—	—	—	7.83 ± 1.96	—	—	—	45.40 ± 0.89	
Vishnyakovskoye	♀	30	25.07.2001	9.18 ± 0.14	5.07 ± 0.09	—	—	—	5.07 ± 0.67	—	—	—	55.23 ± 0.89	—
	♂	2		7.40 ± 0.10	3.35 ± 0.05	—	—	—	4.00 ± 2.00	—	—	—	45.27 ± 0..27	—
Tibizkol	♀	30	03.07.2001	10.41 ± 0.23	5.36 ± 0.16	—	—	—	13.00 ± 1.59	—	—	—	51.49 ± 0.51	—
	♂	3		8.03 ± 0.15	3.50 ± 0.26	—	—	—	12.33 ± 1.88	—	—	—	43.59 ± 0.48	—
Aktoban	♀	30	26.06.2001	8.96 ± 0.16	4.95 ± 0.11	—	—	—	7.13 ± 0.23	—	—	—	55.25 ± 0.29	—
	♂	3		8.15 ± 0.35	3.75 ± 0.05	—	—	—	6.25 ± 0.25	—	—	—	46.01 ± 0.46	—
Gashkovo	♀	23	04.07.2001	9.15 ± 0.20	4.45 ± 0.14	—	—	—	6.58 ± 0.89	—	—	—	48.63 ± 0.37	—
	♂	1		7.8	3.1	—	—	—	10	—	—	—	39.74	—
Borki	♀	29	03.07.2001	9.23 ± 0.54	5.28 ± 0.36	—	—	—	8.73 ± 0.49	—	—	—	57.20 ± 1.10	—
	♂	1		6.3	2.5	—	—	—	9	—	—	—	39.68	—
Shamelya	♀	30	02.07.2001	8.95 ± 0.12	4.76 ± 0.08	—	—	—	8.86 ± 1.349	—	—	—	53.18 ± 0.26	—
	♂	1		7.9	3.5	—	—	—	7	—	—	—	44.3	—
Aslykul	♀	22	02.07.2001	8.73 ± 0.20	4.53 ± 0.16	—	—	—	6.67 ± 0.49	—	—	—	51.89 ± 0.36	—
	♂	1		7.1	2.9	—	—	—	12	—	—	—	40.85	—
Ebeyty	♀	30	15.06.2001	9.34 ± 0.21	4.80 ± 0.18	—	—	—	3.75 ± 0.51	—	—	—	51.39 ± 0.45	—
	♂	2		7.05 ± 0.75	3.30 ± 0.50	—	—	—	1	—	—	—	46.81	—
Trebushinoye	♀	56	27.08.2000	8.62 ± 0.95	4.27 ± 0.06	—	—	—	6.33 ± 0.48	—	—	—	49.54 ± 1.32	—
	♂	3		7.44 ± 0.12	3.75 ± 0.24	—	—	—	7.00 ± 1.00	—	—	—	50.40 ± 0.36	—

1	2	3	4	5	6	7	8
Ulzhay	♀	64	11.07.2000	8.60 ± 0.09	4.56 ± 0.10	—	—
	♂	1		9	4.2	—	—
Cherdynskoye	♀	36	18.07.2000	9.43 ± 0.21	4.73 ± 0.11	—	—
	♂	3		7.63 ± 0.47	4.21 ± 0.12	—	—
Medvezhye	♀	75	07.07.2000	10.37 ± 0.16	5.81 ± 0.10	—	—
	♂	2		8.38 ± 0.16	5.16 ± 1.82	—	—
Shamelya	♀	10	06.07.1997	8.11 ± 0.12	3.51 ± 0.14	—	—
	♂	6		7.6 ± 0.05	3.52 ± 0.22	—	—
Ulzhay	♀	20	20.07.1997	6.34 ± 0.14	2.7 ± 0.12	—	—
	♂	1		6.2	2.7	—	—
Ebeyty	♀	10	21.07.1997	8.52 ± 0.17	4.11 ± 0.16	—	—
	♂	1		6.3	3.47	—	—
B. Kureynoye	♀	33	28.06.1996	9.71 ± 0.18	4.53 ± 0.15	—	—
	♂	3		8.62 ± 0.42	4.12 ± 0.33	—	—
Nevidim	♀	40	19.06.1996	8.72 ± 0.15	4.11 ± 0.12	—	—
	♂	6		8.7 ± 0.41	4.1 ± 0.09	—	—
Ulzhay	♀	30	29.07.1995	6.36 ± 0.19	2.70 ± 0.09	—	—
	♂	2		6.20 ± 0.05	2.70 ± 0.10	—	—
Ebeyty	♀	30	26.07.1995	7.35 ± 0.24	3.95 ± 0.14	—	—
	♂	4		6.30 ± 0.40	3.47 ± 0.30	—	—
Shamelya	♀	30	04.07.1995	8.67 ± 0.16	4.71 ± 0.10	—	—
	♂	3		7.95 ± 0.75	3.90 ± 0.30	—	—

Appendix 22. **Ratio of female parameters to male parameters by 37 populations**

Index	*tl*	*al*	*cl*	*aw*	*de*	*ed*	*sf-r*	*fl*	*la*	*hw*	*ra*, %	*f/a*
min	0.93	0.97	0.84	0.74	0.34	0.46	0.28	0.57	0.62	0.87	0.88	0.34
max	1.53	2.11	1.56	1.58	1.21	1.30	3.75	1.64	1.33	2.88	1.44	1.38
σ	0.15	0.25	0.17	0.30	0.32	0.30	0.72	0.23	0.23	0.90	0.13	0.22
M	1.21*	1.33*	1.13*	1.18	0.75	0.82	1.15	1.08	1.08	1.44	1.09*	0.89*
m	0.02	0.04	0.03	0.05	0.05	0.05	0.12	0.04	0.04	0.15	0.02	0.04
C_v, %	12	19	15	26	42	37	62	21	21	63	12	25

Note. * Distinctions are significant at $p < 0.05$.

Appendix 23. **Estimation of significance of distinctions of morphometric parameters of shrimps from compared reservoirs on value *t*-Student criterion**

Location	Kulundinskoye	Teke	Bayan-Tuhum	*A. sinica*	Location	Kulundinskoye	Teke	Bayan-Tuhum	*A. sinica*
1	2	3	4	5	1	2	3	4	5
	ra					*fl*			
Nevidim	−1.23	**−4.29**	**−2.59**	**−6.56**	Nevidim	**−4.42**	**−2.41**	0.86	**4.65**
Kulundinskoye		**−3.38**	**−1.90**	**−5.93**	Kulundinskoye		1.05	**4.09**	**11.32**
Teke			1.08	**−2.42**	Teke			**2.81**	**8.23**
Bayan-Tuhum				**−3.16**	Bayan-Tuhum				**3.79**

Appendix 21 (continued)

9	10	11	12	13	14	15
—	7.50 ± 1.52	—	—	—	53.02 ± 0.79	—
—	2	—	—	—	46.67	—
—	2.20 ± 0.20	—	—	—	50.16 ± 0.63	—
—	3.40 ± 0.5	—	—	—	55.06 ± 0.56	—
—	2.05 ± 0.13	—	—	—	56.03 ± 0.86	—
—	2.66 ± 0.88	—	—	—	—	—
—	3.72 ± 0.32	0.08 ± 0.01	—	—	43.21 ± 0.79	2.08 ± 0.30
—	6 ± 0.63	0.07 ± 0.01	—	—	46.05 ± 0.98	1.99 ± 0.46
—	2.63 ± 0.23	0.18 ± 0.03	—	—	42.86 ± 0.56	6.63 ± 0.26
—	9.5	0.19	—	—	43.55	7.04
—	5.13 ± 0.28	0.12 ± 0.02	—	—	48.24 ± 0.97	2.93 ± 0.36
—	4.5	0.11	—	—	55.08	3.17
—	11.05 ± 0.36	0.25 ± 0.01	—	—	46.39 ± 1.20	5.56 ± 0.26
—	14.3 ± 0.77	0.23 ± 0.04	—	—	47.67 ± 2.46	5.61 ± 0.91
—	12.9 ± 0.28	0.21 ± 0.02	—	—	47.13 ± 1.32	5.12 ± 0.25
—	14.2 ± 0.53	0.25 ± 0.01	—	—	47.13 ± 2.31	6.11 ± 0.20
—	8.81 ± 1.30	0.18 ± 0.01	—	—	42.45 ± 1.30	6.63 ± 0.23
—	9.50 ± 0.50	0.19 ± 0.00	—	—	43.55 ± 0.46	7.04 ± 0.19
—	2.56 ± 0.10	0.08 ± 0.01	—	—	53.71 ± 1.75	2.13 ± 0.32
—	4.50 ± 0.50	0.11 ± 0.03	—	—	55.03 ± 3.49	3.17 ± 0.65
—	6.11 ± 0.41	0.23 ± 0.01	—	—	54.33 ± 0.98	4.77 ± 0.29
—	6.00 ± 1.00	0.14 ± 0.04	—	—	49.10 ± 4.63	3.46 ± 0.89

Appendix 23 (continued)

1	2	3	4	5	1	2	3	4	5
	tl					*de*			
Nevidim	**−18.53**	**8.92**	**8.75**	**12.26**	Nevidim	**7.12**	−0.17	−1.11	**4.96**
Kulundinskoye		**−3.46**	**−2.57**	0.75	Kulundinskoye		**−6.02**	**−8.69**	**−2.36**
Teke			0.52	**3.67**	Teke			−0.78	**3.87**
Bayan-Tuhum				2.76	Bayan-Tuhum				**6.78**
	al					*ed*			
Nevidim	**15.22**	0.50	**2.39**	0.89	Nevidim	**7.53**	−0.58	−0.42	**5.64**
Kulundinskoye		**−7.36**	**−3.84**	**−6.10**	Kulundinskoye		**−7.20**	**−6.95**	**−2.28**
Teke			1.73	0.49	Teke			0.00	**4.78**
Bayan-Tuhum				1.28	Bayan-Tuhum				**3.73**
	aw					*la*			
Nevidim	**3.69**	0.83	**−10.32**	1.98	Nevidim	**13.06**	**9.77**	−0.89	**13.33**
Kulundinskoye		**−2.09**	**−16.10**	−0.46	Kulundinskoye		1.81	**−8.51**	**7.40**
Teke			**−10.31**	1.39	Teke			**−8.84**	**3.54**
Bayan-Tuhum				**12.63**	Bayan-Tuhum				**11.67**
	sf-r					*hw*			
Nevidim	**2.41**	0.58	**14.79**	**4.67**	Nevidim	**9.17**	**2.21**	**−16.07**	0.70
Kulundinskoye		−1.62	**9.93**	1.69	Kulundinskoye		**−2.76**	**−29.87**	**−4.32**
Teke			**11.66**	**3.99**	Teke			−12.59	−1.10
Bayan-Tuhum				**−7.62**	Bayan-Tuhum				**−10.51**

Note. Significant distinctions are assigned by fat font.

Appendix 24. **Dynamics of sexual structure and fertility of Artemia in parthenogenetic and bisexual populations**

Lake	Index	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	*M*	σ	C_v, %
M. Medvezhye	F_c	25.7	18.9	28.3	12.9	24.1	36.5	11	10.1	19	30.9	21.7	8.88	40.9
	♀, %	100	100	100	—	100	99.9	100	99.9	100	99.9	100	0.05	0.05
B. Medvezhye	F_c	25.7	18.9	28.3	12.9	24.1	28	12.5	13.4	29.4	28.5	22.2	7.05	31.8
	♀, %	100	100	100	—	100	99.8	100	99.9	100	99.9	100	0.07	0.07
Nevidim	F_c	10.2	26.9	26.1	20.0	—	14.2	24.1	15.5	0	29.9	18.6	9.56	51.5
	♀, %	100	99.5	99.8	99.7	—	96.8	100	98.4	100	100	99.4	1.09	1.09
Shamelya	F_c	21	11.5	15.0	9.3	—	14.6	16.1	22.7	—	—	15.7	4.79	30.4
	♀, %	99.3	100	99.8	100	—	100	99.4	100	—	—	99.8	0.31	0.31
B. Kureynoye	F_c	4	23.2	21.3	39.2	12.6	9	30.5	26.8	14.2	25.7	20.6	10.7	51.8
	♀, %	100	99.4	99.8	100	99.6	99.6	96.6	99.8	99.8	98.6	99.3	1.04	1.05
Vishnyakovskoye	F_c	—	—	26.2	12	—	26	30.3	17.5	27.4	22.6	23.1	6.36	27.5
	♀, %	—	—	100	100	—	99.9	100	100	99.7	100	99.9	0.11	0.11
Aktoban	F_c	—	—	21.3	—	—	12.2	17.8	60.7	—	22	26.8	19.3	72.2
	♀, %	—	—	100	—	—	100	100	100	—	100	100	0	0
Solenoye 18	F_c	15.7	—	—	—	—	15.6	—	12.9	—	—	14.7	1.59	10.8
	♀, %	100	—	—	—	—	99.9	—	100	—	—	100	0.06	0.06
Gashkovo	F_c	—	—	24.6	20.2	—	16.9	12	34.3	—	—	21.6	8.46	39.2
	♀, %	—	—	98.2	99.7	—	99.7	99.8	100	—	—	99.5	0.73	0.73
Filatovo	F_c	—	—	25.9	34.9	—	23.4	29.5	16.1	—	—	26	7	27
	♀, %	—	—	99.9	100	—	99.5	100	100	—	—	99.9	0.22	0.22
Trebushinoye	F_c	—	38.5	40.6	21.7	—	14	27	23	0	12	22.1	13.6	61.5
	♀, %	—	100	99.7	99	—	99.7	99.6	100	100	100	99.8	0.35	0.35
Cherdynskoye	F_c	—	—	—	—	—	13.4	14.9	29	9.6	26.5	18.7	8.55	45.8
	♀, %	—	—	—	—	—	100	100	100	100	100	100	0	0
N.-Georgievskoye	F_c	—	—	—	—	—	45.4	49	16.9	23	7	28.3	18.3	64.6
	♀, %	—	—	—	—	—	98.7	98.9	99.8	97.8	100	99	0.89	0.9
Ulzhay	F_c	18.7	—	18.5	—	—	10.9	34	25.8	19.2	8	19.3	8.73	45.2
	♀, %	95.8	—	99.9	—	—	100	100	99	100	100	99.2	1.56	1.57
Ebeyty	F_c	6.7	—	12.8	—	—	—	24.7	28.8	13.3	12	16.4	8.48	51.8
	♀, %	96.8	—	100	—	—	—	99.9	99.7	100	100	99.4	1.28	1.29
Sobachye	F_c	—	8.6	—	—	—	11.6	9.1	41	—	—	17.6	15.7	89.1
	♀, %	—	100	—	—	—	80	97.8	99.7	—	—	94.4	9.63	10.2
Voskresenskoye	F_c	—	—	—	—	—	10.4	22.3	75	—	—	35.9	34.4	95.8
	♀, %	—	—	—	—	—	99.9	100	99.9	—	—	99.9	0.06	0.06
Setovo	F_c	—	—	18.5	11.5	—	21	8.3	61.8	—	—	24.2	21.6	89.3
	♀, %	—	—	100	100	—	99.8	100	99.7	—	—	99.9	0.14	0.14
Soleniy Kulat	F_c	—	—	—	6.8	—	6.4	33.2	36.6	25.2	—	21.6	14.3	66.3
	♀, %	—	—	—	99.3	—	100	99.9	99.7	100	100	99.8	0.28	0.28
In General, for all parthenogenetic populations...	F_c	16.0	20.9	23.6	18.3	20.3	18.3	22.6	29.9	16.4	20.5	**22.6**	13.0	55.0
	♀, %	99	99.8	99.8	99.7	99.9	98.5	99.6	99.8	99.8	99.9	**99.3**	1.01	0.95
Tus	F_c	—	—	—	—	—	22.2	—	—	—	21.6	21.9	0.4	1.9
	♀, %	—	—	—	—	—	57.0	—	—	—	68.2	62.6	7.9	12.7
Svatikovo	F_c	—	—	—	—	—	15.7	—	—	—	38.6	27.2	16.2	59.5
	♀, %	—	—	—	—	—	41.6	—	—	—	63.6	52.6	15.6	29.6
In General, for all bisexual populations...	F_c	—	—	—	—	—	19.0	—	—	—	30.1	**24.6**	8.3	30.7
	♀, %	—	—	—	—	—	49.3	—	—	—	65.9	**57.6**	11.7	21.1

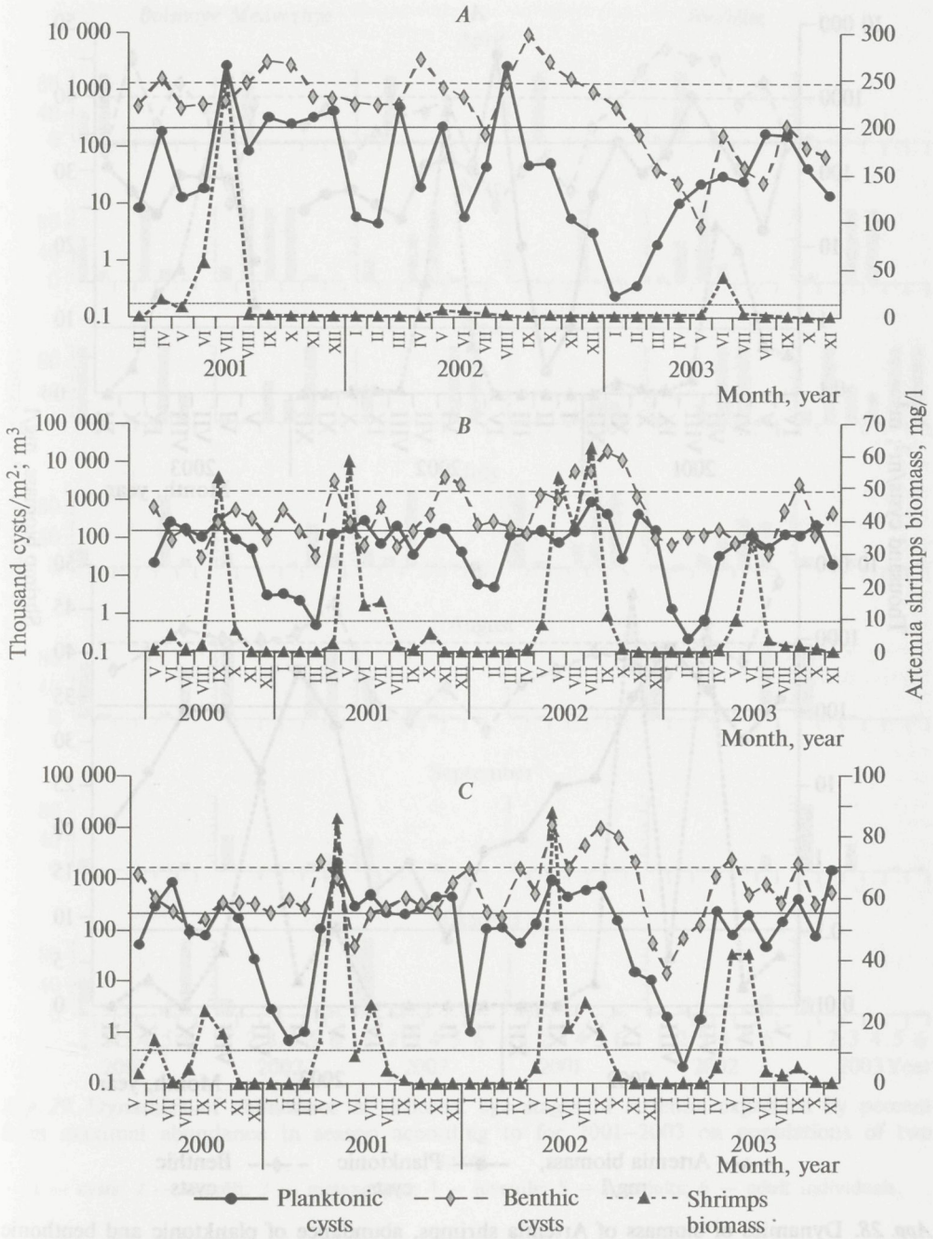
Note. ♀, % — percent of female in population. The average values for the parthenogenetic and bisexual populations.

Appendix 25. **Average seasonal weight of Artemia adult female and male in the investigated populations in the period 1995–2004, mg**

Lake	Weight of female											Weight of male									
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
B. Medvezhye	6.8	4.5	6.8	3.7	6.4	5	2	2.6	5.1	5.4						2.8	2	1.5	—	1
M. Medvezhye	6.8	4.5	6.8	3.7	6.4	4.2	2.1	2.7	5.1	5.8						3	—	2.5	5	4
Nevidim	3.5	5.4	5.9	5.7		3.4	3.4	3.5	4.8	4.7		6.6	5.4	3.6		2.6	4.4	3.5	—	
Shamelya	3.4	3.0		1.7		3.4	3.6	4.2	—	—	4					—	3.5	—	—	
N.-Georgievskoye	2.3					6	6	2.9	4.5	3						2.7	1	3	4.5	
Cherdynskoye						3.9	7.5	2.4	2.9	4.3						3.3	—	—	—	
Trebushinoye		11.9		5.8		3.2	4.8	3.7	10	1.8				4.2		2.8	3.9	—	—	
Sobachye		3.3				2.4	2.8	3.8	—							1.6	—	—	—	
B. Kureynoye		4.6	4.6	3.9	5.8	3.8	5.5	2.8	4.9	2.3		4			4	2.7	4	3	—	1
Gashkovo				4.1		3	4.1	4	—					4.0		3	4	—	—	
Vishnyakovskoye			4.9	2.7		3.6	3.5	3.5	5.6	3.3						1.7	2	—	3	
Aktoban			4.4			2.9	3.3	4.6	—	3.3			4			—	2	—	—	
Filatovo			5.6	3.8		5	3.3	2.4	—				2			2.5	—	—	—	
Setovo				2.8		2.6	6.6	5.6	—							—	—	—	—	
Borki						3.8	3.5	3	—							—	2	—	—	
Umreshevo				4.9		4.9	2.9	—	—					6.0		1.9	2	—	—	
Voskresenskoye						3.2	5.7	6	—							—	—	—	—	
Tibizkol						—	3.5	2.2	—							—	2	2.0	—	
Lavrusheno						—	2.7	3.3	—							—	—	1.2	—	
Aslykul						—	4	2.8	—							—	3	—	—	
Tauzatkul						6	5	4.6	—							—	—	5	—	
Soleniy Kulat				2.5		4.3	3.3	3	6	3.9				2.0		—	4	—	4	
Oktyabrskoye						7	3.4	3	—							—	2.8	—	—	
Solenoye 18						3.5	—	1.6	—							3	—	—	—	
Ulzhay			4.6			3.8	3.8	3.3	3.5	2.3	2.1		3			4.3	—	4	—	
Ebeyty			2.8			—	3.3	4.3	3.5	2.8	1.6					2.8	2.8	—	—	
Tus						2.7				2.2						1.9				1.4
Svatikovo						2.5				6.6						2				3
	In general for all populations																			
min — max	1.6–11.9										1.0–6.6									
M	4.18										3.03									
σ	1.59										1.18									
C_v, %	38										39									

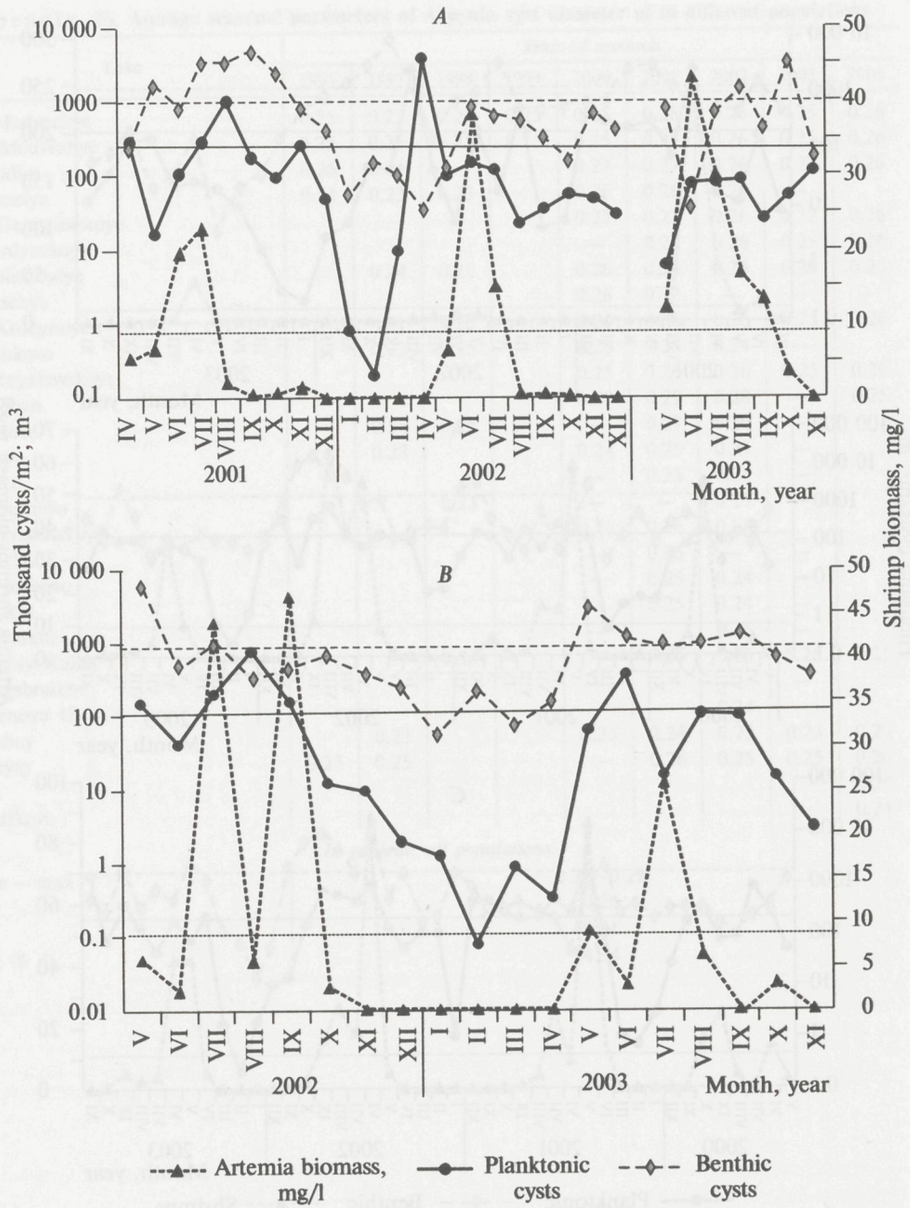
Appendix 26. Average seasonal parameters of Artemia cyst diameter of in different populations

Lake	Years of research								
	1995	1997	1998	1999	2000	2001	2002	2003	2004
B. Medvezhye	0.25	0.25	0.25	0.25	0.25	0.26	0.26	0.25	0.26
M. Medvezhye	0.25	0.25	0.25	0.25	0.25	0.26	0.26	0.25	0.26
Nevidim	0.26	0.24			0.27	0.27	0.26	0.27	0.26
Shamelya	0.24	0.23	0.23		0.26	0.26	0.25	—	
N.-Georgievskoye					0.27	0.27	0.26	0.27	0.26
Cherdynskoye					—	0.26	0.26	0.25	0.26
Trebushinoye		0.24	0.25		0.26	0.26	0.25	0.26	0.25
Sobachye					0.26	0.27	—	—	
B. Kureynoye			0.25		0.25	0.26	0.26	0.25	0.26
Gashkovo		0.23	0.25		0.25	0.25	0.24	—	
Vishnyakovskoye					0.25	0.26	0.26	0.25	0.26
Aktoban					0.29	0.29	0.28	—	0.25
Filatovo		0.24	0.25		—	0.27	0.26	—	
Setovo		0.23			0.24	0.25	0.25	—	
Borki					—	0.25	0.24	—	
Umreshevo			0.23		—	—	0.25	—	
Voskresenskoye					0.25	0.26	0.25		
Tibizkol					—	0.26	—	—	
Lavrusheno					—	0.25	0.24	—	
Aslykul					—	0.25	0.24	—	
Tauzatkul					—	—	0.25	—	
Soleniy Kulat			0.25		—	0.26	0.25	0.26	0.25
Oktyabrskoye					—	—	—	—	
Solenoye 18					—	—	0.24	—	
Ulzhay		0.23			0.25	0.24	0.25	0.25	0.25
Ebeyty	0.25	0.25			—	0.26	0.25	0.25	0.26
Tus									0.26
Svatikovo									0.24
In general, all populations									
min — max					0.23–0.29				
M					0.26				
σ					0.01				
C_v, %					4.34				



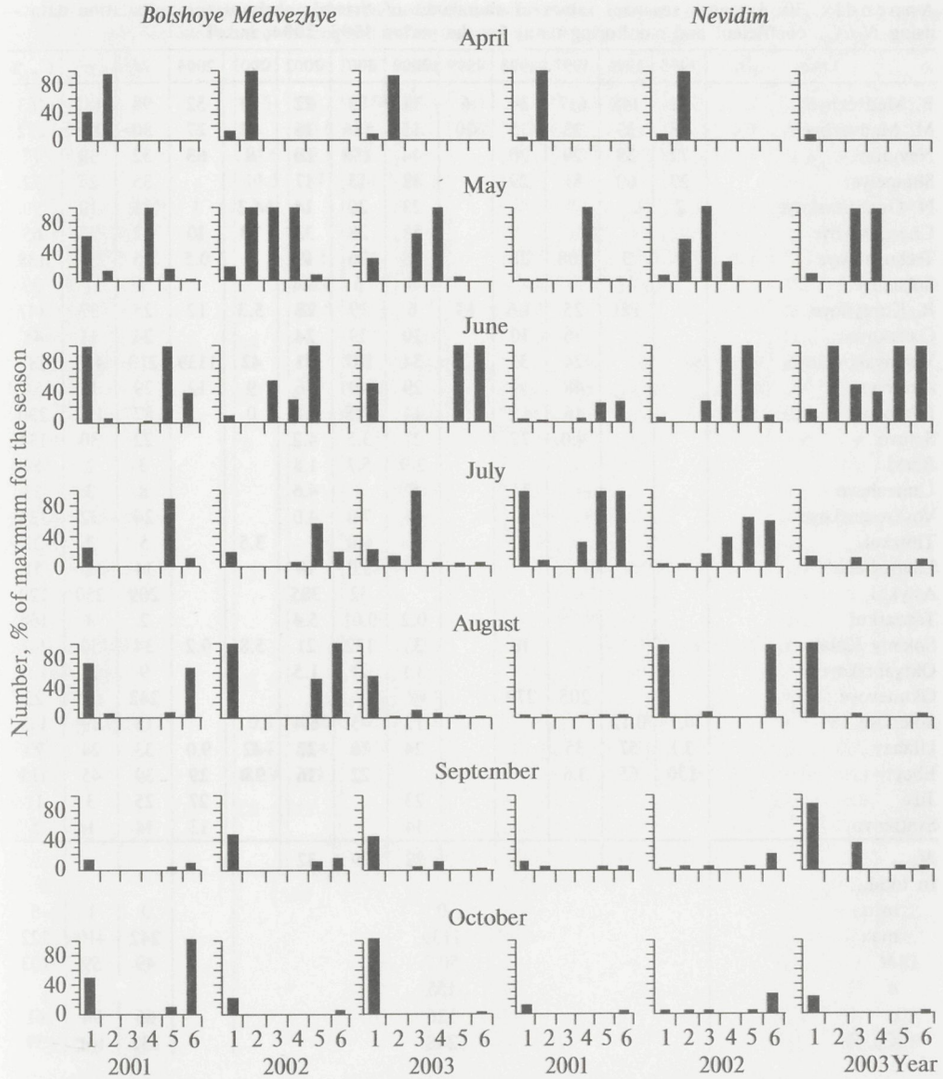
App. 27. Abundance of planktonic and benthonic cysts, biomass of Artemia shrimps in lakes.

A — Nevidim; *B* — B. Medvezhye; *C* — M. Medvezhye.



App. 28. **Dynamics of biomass of Artemia shrimps, abundance of planktonic and benthonic cysts in lakes.**

A **— Vishnyakovskoye;** ***B*** **— Ebeyty.**



App. 29. Dynamics of abundance of different age stages of Artemia expressed by percent from maximal abundance in season according to for 2001–2003 on populations of two lakes.

1 — cysts; 2 — nauplii; 3 — metanauplii; 4 — juvenile; 5 — preadults; 6 — adult individuals.

Appendix 30. **Averages seasonal values of abundance of Artemia shrimps (on calculation data — using N_f/N_{avr} coefficient and monitoring data) for the period 1995–2004, ind./l**

Lake	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	*M*	σ	C_v, %
B. Medvezhye	22	148	617	34	6	**11**	**78**	**22**	**10**	**32**	98	187	183
M. Medvezhye	16	39	23	15	20	**15**	**586**	**16**	**44**	**27**	80	178	222
Nevidim	72	59	29	20		44	**158**	**20**	**8**	**63**	52	39	77
Shamelya	27	60	81	29		18	15	17			35	25	72
N.-Georgievskoye	2					23	20	**14**	**4.2**	1	11	10	90
Cherdynskoye						58	28	33	**79**	10	42	27	65
Trebushinoye	0	3	108	28		38	26	**19**	1	0.5	25	34	138
Sobachye		17				6	5	0.4			7	7	99
B. Kureynoye		121	25	1.6	13	6	19	**23**	**5.3**	12	25	37	147
Gashkovo			16	10		30	39	**24**			24	11	48
Vishnyakovskoye			24	33		34	**187**	**71**	**42**	1139	219	410	187
Aktoban			48			29	40	36	9	12	29	16	54
Filatovo			16	4.2		14	478	**11**	0		87	192	220
Setovo			4.0	72		27	3.5	4.2			22	30	134
Borki						2.9	5.7	1.8			3	2	59
Umreshevo				11		8	8	4.6			8	3	33
Voskresenskoye						61	7.0	4.0			24	32	134
Tibizkol							6.0		3.5		5	2	37
Lavrusheno							9.0	19			14	7	51
Aslykul							32	385			209	250	120
Tauzatkul						0.2	0.01	5.4			2	3	164
Soleniy Kulat				10		33	132	21	5.8	0.2	34	50	147
Oktyabrskoye						3.1	21	1.5			9	11	127
Okunevoye			205	279							242	52	22
Solenoye 18	0.7	0.12				12	45	6.4			13	19	145
Ulzhay	3.1	57	35			24	76	**22**	42	9.0	33	24	73
Ebeyty	130	65	3.6				22	**16**	**9.0**	**29**	39	45	115
Tus						23				27	25	3	11
Svatikovo						14				13	14	1	5
M_{year}						22	79	32					
In total...													
min						0					2	1	5
max						1139					242	410	222
M						50.7					49	59	103
n						155							
σ						126					65	94	61
C_v, %						248					132	161	59

Note. Monitoring researches are noted by fat font.

Appendix 31. **Averages seasonal values of biomass of Artemia shrimps (on calculation data — using of B_f/B_{avr} coefficient and monitoring data) for the period 1995–2004, mg/l**

Lake	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	*M*	σ	C_v, %
B. Medvezhye	15	94.2	9.9	19.4	47	**9.8**	**14.6**	**24.7**	**6.3**	**7.8**	24.9	25.7	103
M. Medvezhye		40.6	32.5	5.7	48	**9**	**22.1**	**15.9**	**11.1**	**4.8**	21.1	14.9	71
Nevidim	54.6	79.1	15.2	61		12.2	**42.8**	**3.7**	**6.5**	**7.7**	31.4	26.7	85
Shamelya	14.5	57	124.2	29.8		3	5.4	4			34.1	41	120
N.-Georgievskoye	1.4					34.8	25.2	7.6	5.7	1.2	12.7	12.8	101
Cherdynskoye						72.1	25.5	50	34.1	3.2	37	23.2	63
Trebushinoye		2.1	24	52.8		25.8	33.7	2.5	0.02	0.4	17.7	18.3	104
Sobachye		18.6				5.8	4.5	0.1			7.2	6.9	95
B. Kureynoye		87.5	76.8	1.5	151.9	6.1	6.3	7.7	6	5.2	38.8	50.9	131
Gashkovo			3.5	20.1		26.4	13.7	2.1			13.2	9.3	71
Vishnyakovskoye			30.9	18		91.6	**7.6**	12	**18**	53.9	33.1	30	91
Aktoban			64.5			38.3	21	21.6	2.9	25.4	29	19	66
Filatovo			40	1.43		3.8	13.5	5.2	0		10.7	15.1	142
Setovo			7.2			0.6	1.2	0.6			2.4	2.8	116
Borki						1.3	8.9	0.2			3.5	3.9	111
Umreshevo				23.8		1	6.6	1			8.1	9.4	116
Voskresenskoye						57	2.9	2.8			20.9	25.5	122
Tibizkol							7.3		4.7		6	1.3	22
Lavrusheno							9.4	5.4			7.4	2	27
Aslykul							4.8	14.8			9.8	5	51
Tauzatkul						0.5	0.04	8.7			3.1	4	130
Soleniy Kulat				1.5		80.8	180.6	10.4	6.4	0.3	46.7	66.1	142
Oktyabrskoye						0.4	2	0.1			0.8	0.8	103
Okunevoye			220	89.9							154.9	65	42
Solenoye 18	0.9	0.4				17.9	6.5	5.5			6.2	7.1	113
Ulzhay	1.4	8.4	46.7			34.2	21.7	**16.8**	51.5	4.6	23.2	17.9	77
Ebeyty	81.9	73	5.2				7.8	**21.5**	**10.8**	**6.3**	29.5	33.3	113
Tus						21.2				37.8	29.5	11.8	40
Svatikovo						19.7				3.1	11.4	11.8	103
M_{year}						23.9	19.1	9.8	11.7	11.6			
In total...							*All years*					*All lakes*	
min							0				0.8	0.8	22
max							220				154.9	66	142
M							23.8				23.3	19	92
n							144					29	
σ							34				28	18	33
C_v, %							142				122	93	36

Note. Monitoring researches are noted by fat font.

Appendix 32. **Averages seasonal values of abundance of planktonic Artemia cysts (on calculation data – using of N_f/N_{avr} coefficient, and monitoring data) for the period 1995–2004, ind./l**

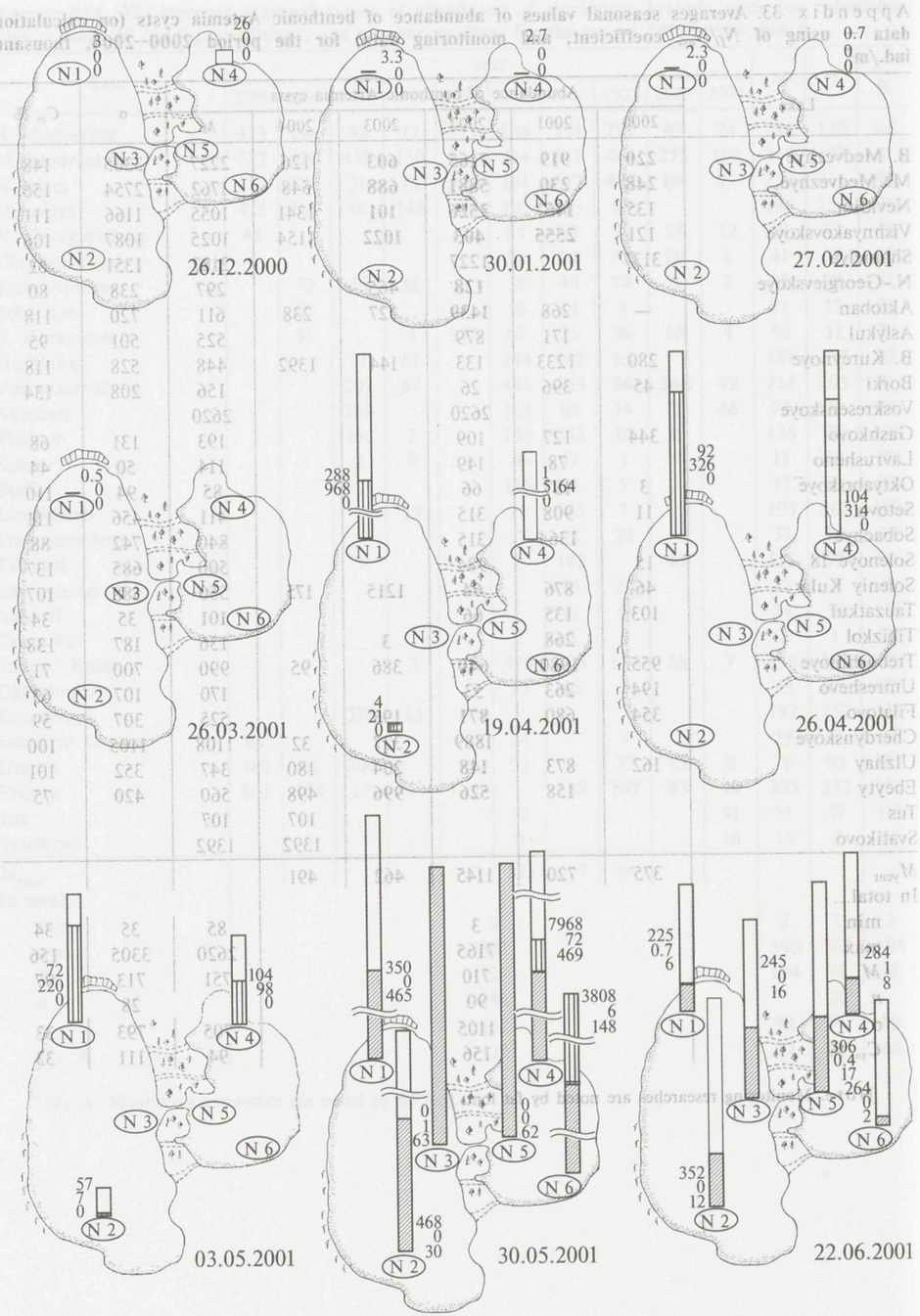
Lake	Year										M	σ	C_v, %
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004			
B. Medvezhye	373	194	92	72	375	**136**	**151**	**297**	**99**	74	186	120	64
M. Medvezhye	373	420	452	150	346	**414**	**317**	**461**	**275**	193	340	107	31
Nevidim	132	581	31	75		161	**517**	**403**	**80**	93	230	211	91
Shamelya	475	165	16	148		202	283	81			196	150	76
N.-Georgievskoye	44					65	63	**71**	55	12	52	22	42
Cherdynskoye						98	34	52	20	1	41	37	90
Trebushinoye		72	26	18		38	40	**78**	6	2	35	28	81
Sobachye		21				16	44	3			21	17	81
B. Kureynoye		91		4	157	62	25	**36**	68	4	56	51	92
Gashkovo			91	61		244	447	63			181	167	92
Vishnyakovskoye			207	62		448	**365**	**86**	**560**	49	254	205	81
Aktoban			160			169	69	14	2	46	77	72	94
Filatovo			166	2		134	442	**10**	0		126	171	136
Setovo			2	9		26	17	3			11	10	89
Borki						116	96	5			72	59	82
Umreshevo				19		10	735	7			193	362	188
Voskresenskoye						27	48	24			33	13	40
Tibizkol							182		44		113	98	86
Lavrusheno							25	24			25	1	3
Aslykul							61	6			34	39	116
Tauzatkul						2	3	2			2	1	25
Soleniy Kulat				5		473	303	124	26	7	156	192	123
Oktyabrskoye						13	26	0			13	13	100
Okunevoye			378	15							197	257	131
Solenoye 18	60					24		4			29	28	97
Ulzhay	180	46	260			53	6	**37**	15	9	76	93	123
Ebeyty	801	158	27				138	**197**	**83**	18	203	272	134
Tus						10				91	51	57	113
Svatikovo						9				16	13	5	40
M_{year}						123	177	84					
In total...													
min						0					2	1	3
max						801					340	362	188
M						129					104	98	88
n						148						29	
σ						162					90	96	39
C_v, %						126					87	97	44

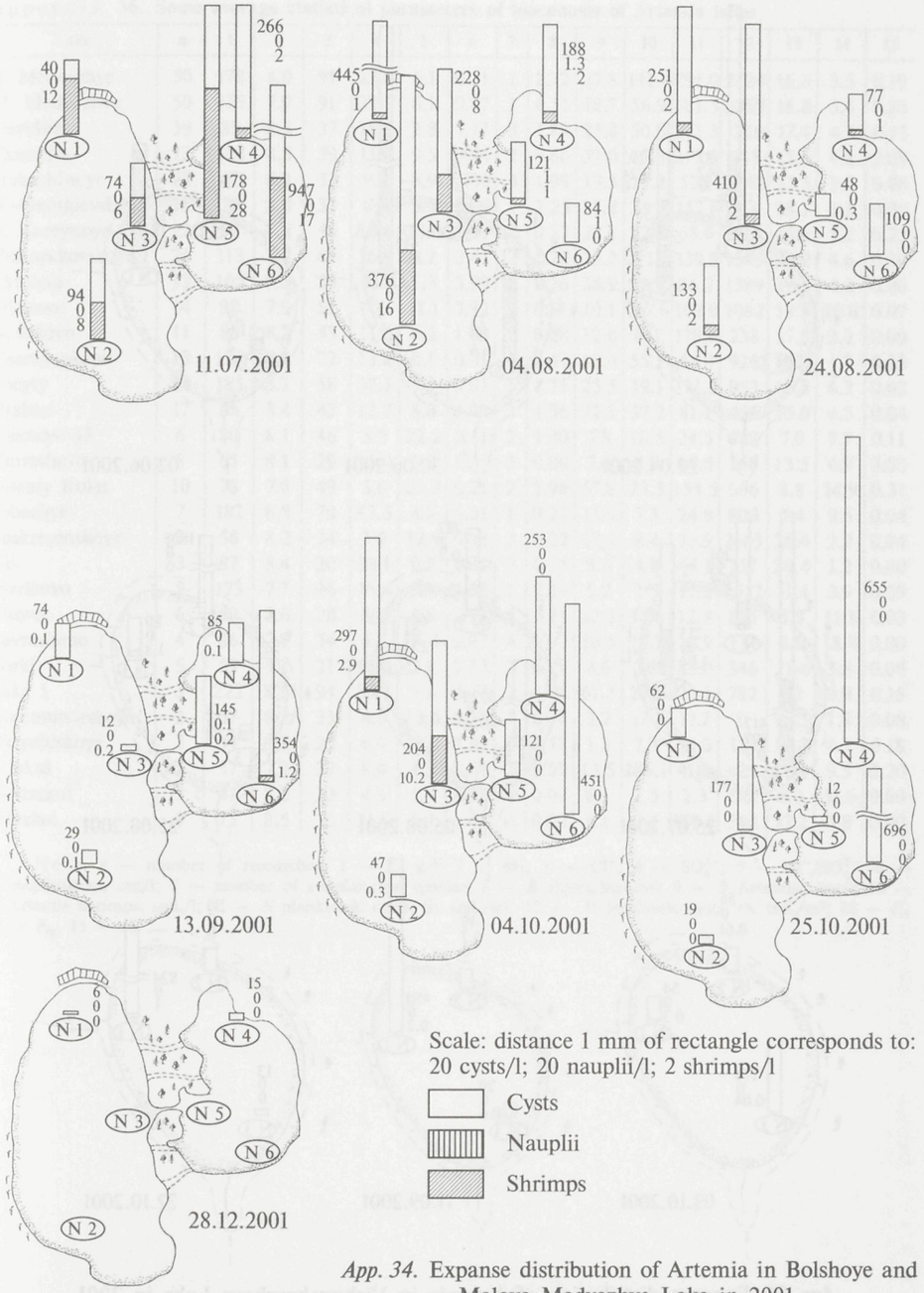
Note. Monitoring researches are noted by fat font.

Appendix 33. **Averages seasonal values of abundance of benthonic Artemia cysts (on calculation data – using of N_f/N_{avr} coefficient, and monitoring data) for the period 2000–2004, thousand ind./m²**

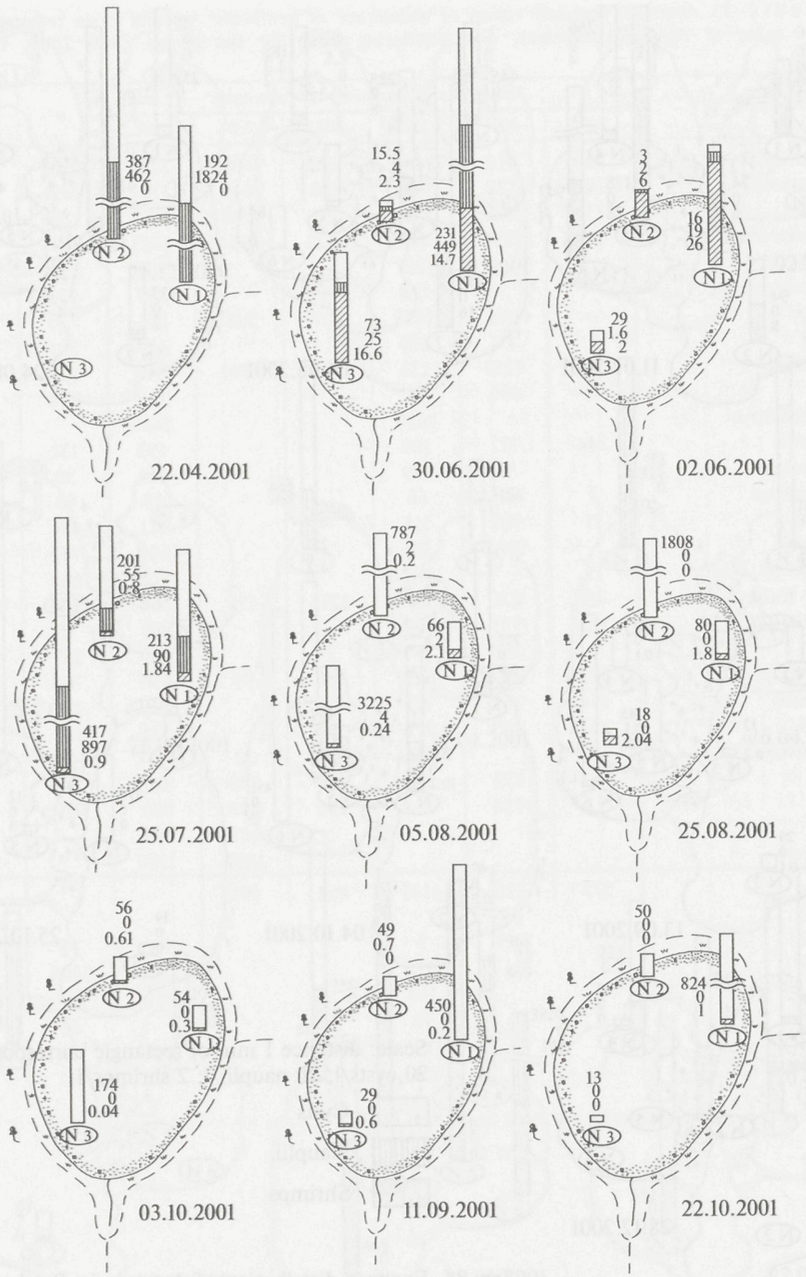
Lake	Abundance of benthonic Artemia cysts						σ	C_v, %
	2000	2001	2002	2003	2004	M		
B. Medvezhye	**220**	**919**	**7165**	**603**	126	2227	3305	148
M. Medvezhye	**248**	**230**	**5881**	**688**	548	1762	2754	156
Nevidim	135	**1457**	**2526**	**101**	1341	1055	1166	111
Vishnyakovskoye	121	**2555**	**403**	**1022**	1154	1025	1087	106
Shamelya	3137		1227			2182	1351	62
N.-Georgievskoye			**128**	465		297	238	80
Aktoban	—	268	**1439**	127	238	611	720	118
Aslykul		171	879			525	501	95
B. Kureynoye	280	1233	133	144	1392	448	528	118
Borki	45	396	26			156	208	134
Voskresenskoye			2620			2620		
Gashkovo	344	127	109			193	131	68
Lavrusheno		78	149			114	50	44
Oktyabrskoye	3	187	66			85	94	110
Setovo	11	908	315			411	456	111
Sobachye		1364	315			840	742	88
Solenoye 18	15		984			500	685	137
Soleniy Kulat	46	876	64	1215	175	550	588	107
Tauzatkul	103	135	66			101	35	34
Tibizkol		268		3		136	187	138
Trebushinoye	955	1980	**640**	386	95	990	700	71
Umreshevo	194	263	53			170	107	63
Filatovo	354	680	**871**	193		525	307	59
Cherdynskoye			1889	327	32	1108	1105	100
Ulzhay	162	873	**148**	204	180	347	352	101
Ebeyty		158	**526**	**996**	498	560	420	75
Tus					107	107		
Svatikovo					1392	1392		
M_{year}	375	720	1145	462	491			
In total...								
min			3			85	35	34
max			7165			2620	3305	156
M			710			751	713	97
n			90				28	
σ			1105			705	793	33
C_v, %			156			94	111	33

Note. Monitoring researches are noted by fat font.





App. 34. Expanse distribution of Artemia in Bolshoye and Maloye Medvezhye Lake in 2001.
Numerals indicate number of individuals (ind./l).



App. 35. Expanse distribution of Artemia in Vishnyakovskoye Lake in 2001. Designations are the same, as in App. 34.

Appendix 36. **Some average statistical parameters of biocenosis of Artemia lakes**

Lake	*n*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B. Medvezhye	50	178	8.0	91	23.0	6.1	0.11	1	2.72	17.8	141.4	291.0	2124	16.6	3.5	0.19
M. Medvezhye	50	175	7.9	91	22.9	6.1	0.07	1	4.51	18.7	56.9	181.5	2369	16.8	3.4	0.25
Nevidim	39	85	8.3	37	18.8	2.8	1.17	3	1.89	23.8	50.5	271.3	1210	17.4	4.3	0.13
Shamelya	13	112	8.3	59	11.8	9.5	0.94	2	0.66	32.0	27.3	212.2	685	11.6	4.2	0.09
Trebushinoye	22	62	8.2	32	9.5	6.9	5.00	3	1.99	19.3	21.2	53.1	1242	22.5	3.5	0.08
N.-Georgievskoye	16	70	8.8	33	8.8	5.5	0.39	3	2.23	15.8	28.4	157.1	454	28.1	3.1	0.00
B. Kureynoye	22	87	8.2	46	10.6	15.0	1.49	2	0.22	23.1	22.2	68.6	399	16.6	5.2	0.25
Vishnyakovskoye	26	113	8.2	46	26.9	2.7	0.41	2	1.20	25.2	211.2	339.5	1549	22.2	4.6	0.30
Aktoban	13	105	8.3	54	14.3	5.3	3.99	2	0.16	28.9	28.9	96.2	1589	19.3	4.2	0.06
Filatovo	14	90	7.9	52	7.6	11.1	3.92	2	0.91	10.1	167.6	109.0	1082	13.5	10.6	0.07
Gashkovo	11	85	8.2	43	11.0	6.2	1.09	2	0.28	12.0	17.7	178.6	238	17.5	2.2	0.09
Cherdynskoye	13	135	8.4	72	13.8	8.1	0.01	1	0.43	40.4	55.2	44.0	926	13.0	1.7	0.05
Ebeyty	28	185	8.1	58	57.3	2.3	0.01	1	1.75	25.5	19.1	171.4	953	15.8	4.2	0.02
Ulzhay	17	86	8.4	43	12.2	8.8	1.02	3	1.06	32.1	37.2	81.1	456	15.0	4.5	0.04
Solenoye 18	6	80	8.1	46	5.9	22.2	0.11	2	1.80	7.8	18.5	24.5	938	7.0	7.7	0.11
Umreshevo	8	65	8.1	29	15.0	2.7	5.35	3	0.09	7.4	8.2	86.5	168	13.5	4.9	0.00
Soleniy Kulat	10	78	7.6	49	3.0	25.2	0.21	2	5.98	57.8	23.3	154.5	666	8.8	14.9	0.31
Sobachye	7	182	8.8	70	43.5	4.8	0.21	1	0.27	11.0	7.3	24.8	800	5.4	9.5	0.04
Voskresenskoye	7	58	8.2	34	3.9	12.9	0.98	3	0.22	17.4	8.4	36.9	2163	28.4	2.2	0.04
Tus	3	87	8.4	20	39.1	0.7	0.01	2	0.75	8.0	4.8	44.1	117	20.4	1.2	0.00
Svatikovo	2	173	7.7	96	16.4	7.9	0.00	1	2.14	5.2	2.5	11.2	1517	21.4	3.9	0.39
Setovo	6	59	8.6	28	8.4	4.8	2.73	4	0.11	32.2	15.6	12.8	875	5.5	11.1	0.03
Lavrusheno	4	86	7.8	54	3.2	26.3	0.87	4	0.03	10.5	11.7	24.9	114	4.8	18.8	0.00
Borki	5	59	9.1	21	14.0	2.1	3.37	3	0.23	4.6	3.8	85.0	346	21.4	3.8	0.06
Lake 1	3	222	8.5	94	53.3	2.4	0.17	2	0.06	61.3	27.6	70.1	782	9.2	0.9	0.16
Kommunarskoye	2	57	8.2	33	4.0	12.6	0.48	4	0.02	3.2	17.1	17.7	0	15.5	1.8	0.08
Oktyabrskoye	3	54	8.3	29	6.4	11.0	2.80	4	0.17	1.2	7.3	14.0	113	11.8	4.1	0.18
Aslykul	3	57	7.9	29	8.4	4.7	0.38	2	0.02	13.5	186.1	41.9	425	14.6	9.5	2.20
Tauzatkul	3	41	8.2	22	4.3	9.4	8.32	4	0.07	6.1	2.5	2.3	90	0.0	51.6	0.00
Tibizkol	3	72	8.5	35	11.0	4.5	1.63	4	0.02	8.1	2.4	180.1	344	17.2	3.8	0.00

Note. *n* — number of researches; 1 — Σ_i, g/l; 2 — pH; 3 — Cl^-; 4 — SO_4^{2-}; 5 — Cl^-/SO_4^{2-}; 6 — *B* zooplankton, mg/l; 7 — number of zooplankton species; 8 — *B* phytoplankton; 9 — *B* Artemia, mg/l; 10 — *N* Artemia shrimps, ind./l; 11 — *N* planktonic cysts, th. ind./m^3; 12 — *N* benthonic cysts, th. ind./m^2; 13 — F_c, 14 — F_{eg}, 15 — F_n.

Appendix 37. **Averages seasonal values of basic parameters of biocenosis of Artemia lakes**

Lake	Year	Designations of basic parameters																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
B. Medvezhye	1995	110	8	62	13	7.7	0.36	2	0.66	15	22	373		22	4	0.18	0.25	6.8	25.7
M. Medvezhye		110	8	62	13	7.7	0.36	2	0.66	15	16	373		22	4	0.18	0.25	6.8	25.7
Nevidim		75	8.1	38	13	4.4	0.52	5	1.55	54.6	72	132		6	4	0.18	0.26	3.5	25.7
Shamelya		161	8.2	79	21	5.4	0.41	2	1.15	14.5	27	475		15	4	0.18	0.24	3.4	10.2
N.-Georgievskoye		77	8.9	46	4	14.5	0.24	3	0.57	1.4	2	44		0	0	0	0.25	2.3	
Solenoye 18		83	8.1	51	5	12.7	0	1	3.48	0.9	0.7	60		12	4	0.18	0.28	7	
Ulzhay		54	8	28	6	6.6	12	2	7.84	1.4	3.1	180		0	0	0	0.21	2.2	
Ebeyty		210	7.9	64	68	1.3	0.12	2	1.55	81.9	130	801		3	4	0.18	0.25	2.4	
B. Medvezhye	1996	145	8.1	79	10	16.8	0.53	2		94.2	148	194		12	0	0		4.5	18.9
M. Medvezhye		145	8.1	79	10	16.8	0.59	2		40.6	39	420		0	0	0		4.5	18.9
Nevidim		90	7.9	44	20	3.3	0.5	3		79.1	59	581		23	4	0.18		5.4	18.9
Shamelya		147	8.1	79	11	10.5	0.32	2		57	60	165		8	4	0.18	0.24	3	26.9
Trebushinoye		68	7.8	41	5.5	16	19.9	6		2.1	3	72		35	4	0.18		12	
Sobachye		180	8.7	82	11	13	0.05	2		18.6	17	21		5	4	0.18		3.3	
B. Kureynoye		81	7.9	49	1	94.5	7.27	2		87.5	121	91		19	4	0.18		4.6	11.5
Solenoye 18		66	8.8	40	2	49.5	0.6	4		0.4	0.12	130		0	0	0			
Ulzhay		49	8	28	1	64.8	0.39	5		8.4	57	46		0	0	0			
Ebeyty		144	7.9	76	7	52.4	0	1		73	65	158		0	0	0			
B. Medvezhye	1997	143	8.1	78	21	5.1	0.34	3		9.9	617	92		19	0	0	0.25	6.8	28.3
M. Medvezhye		143	8.1	78	21	5.1	0.5	3		32.5	23	452		27	0	0	0.25	6.8	28.3
Nevidim		135	8.3	51	43	1.8	0.76	3		15.2	29	31		22	4	0.18	0.24	5.9	28.3
Shamelya		146	7.9	107	6	25	2.47	2		124	81	16		11	4	0.18	0.23	3.5	26.1
Trebushinoye		84	8.4	45	13	6.9	0.42	4		24	108	26		37	4	0.18	0.24	7.8	25.9
B. Kureynoye		102	8.3	59	11	9.5	0.2	2		76.8	25	130		17	4	0.18		4.6	15.0
Gashkovo		119	8.3	67	11	12.5	3.16	3		3.5	16	91		21	4	0.18	0.23	4.4	
Vishnyakovskoye		199	8	85	51	2.3	0.07	3		30.9	24	207		22	4	0.18		4.9	21.3
Aktoban		162	8.1	91	21	5.9	0.09	2		64.5	48	160		17	4	0.18	0.25	4.4	26.2
Filatovo		73	8	47	4	20.3	1.57	3		40	16	166		22	4	0.18	0.24	5.6	24.6
Setovo		74	8.5	43	7	8.6	0.24	4		7.2	4	2		15	4	0.18	0.23		
Ulzhay		63	8.1	32	10	4.3	1.55	4		46.7	35	260		15	4	0.18	0.23	4.6	
Ebeyty		250	8.6	82	92	1.2	0	1		5.2	3.6	27		9	4	0.18	0.25	2.8	
B. Medvezhye	1998	225	8.3	121	30	5.5	0	1		19.4	34	72		11	0	0	0.25	3.7	12.9
M. Medvezhye		225	8.3	121	30	5.5	0	1		5.7	15	150		10	0	0	0.25	3.7	12.9
Nevidim		159	8.5	80	28	4	0.19	3		61	20	75		16	4	0.18	0.22	5.7	12.9
Trebushinoye		96	7.8	49	17	3.9	0.1	3		52.8	28	18		0	0	0	0.25	5.8	34.9
B. Kureynoye		116	8.3	64	15	5.6	0.02	3		1.5	1.6	4		27	0	0	0.25	3.9	9.3
Gashkovo		154	7.1	82	21	5.3	0	1		20.1	10	61		14	0	0	0.25	4.1	
B. Medvezhye	1999	185	7.8	110	25	6	0	1		47	6	375		20	0	0	0.25	6.4	24.1
M. Medvezhye		186	7.8	110	25	6	0	1		48	20	346		12	0	0	0.25	6.4	24.1
B. Kureynoye		126	7.8	68	17	5.4	0	1		152	13	157		0	0	0		5.8	
B. Medvezhye	2000	225	7.7	113	28	5.7	0.12	2	1.33	9.8	11	136	220	25	3	0.12	0.25	5	28.0
M. Medvezhye		235	7.7	113	25	6.2	0.13	2	1.64	9	15	414	248	34	2	0.11	0.25	4.2	36.5
Nevidim		126	8.6	57	31	2.5	0.52	2	2.14	12.2	44	161	135	10	4	0.18	0.27	3.4	28.0
Shamelya		130	8.6	72	7	19.5	0.8	4	0.73	3	18	202	3137	12	2	0.18	0.26	3.4	14.2
N.-Georgievskoye		100	8.9	46	11	5.7	0.17	3	0.01	34.8	23	65		46	0	0	0.27	6	13.4
Cherdynskoye		189	8.4	105	24	6.4	0.01	2	0.22	72.1	58	98		10	3	0.18		3.9	14.0
Trebushinoye		59	8.6	54	17	4.2	0.44	3	0.12	25.8	38	38	955	12	2	0.18	0.26	3.2	23.4
Sobachye		231	8.8	83	77	1.4	0	1	0.27	5.8	6	16		12	0	0	0.26	2.4	10.9
B. Kureynoye		148	8.3	79	22	5.1	0.11	2	0.06	6.1	6	62	280	8	1	0.09	0.25	3.8	14.6
Gashkovo		107	8.6	49	18	3.8	0.03	2	0.28	26.4	30	244	344	14	2	0.18	0.25	3	15.6
Vishnyakovskoye		192	8.1	79	51	2.1	0.08	2	0.48	91.6	34	448	121	20	4	0.18	0.25	3.6	9.0
Aktoban		171	8.5	88	30	4	0	1	0.07	38.3	29	169		9	3	0.09	0.29	2.9	26.0
Filatovo		160	7.9	95	15	10	0	1	0.91	3.8	14	134	354	20	4	0.09		5	16.9
Setovo		67	8.6	33	12	3.8	0	1	0.04	0.6	27	26	11	15	0	0	0.24	2.6	11.6
Borki		70	9.1	23	16	2	0.99	3	0.44	1.3	2.9	116	45	13	3	0.18		3.8	
Umreshevo		95	8.5	43	25	2.3	4.81	5	0.07	1	8	10	194	15	0	0		4.9	
Voskresenskoye		75	8.2	46	5	14.1	0.14	2	0.16	57	61	27		9	1	0.18	0.25	3.2	
Tauzatkul		41	8.8	24	4	8.5	0.68	3	0.07	0.5	0.2	2	103	0	0	0		6	
Soleniy Kulat		99	7.7	67	2	47.1	0.04	2		80.8	33	473	46	3	3	0.18		4.3	10.4
Oktyabrskoye		54	8.3	36	2	25	0.05	3	0.17	0.4	3.1	13	3	30	4	0.18		7	
Solenoye 18		99	8.3	58	10	8.2	0	1	0.12	17.9	12	24	15	9	6	0.18		3.5	12.2
Ulzhay		143	8.4	61	30	3.7	0.66	2	0.25	34.2	24	53	162	6	4	0.18	0.25	3.8	45.4
Tus		131	8.5	30	60	0.7	0.1	2		21.2	23	10		0	0	0		2.7	21.0
B. Medvezhye	2001	198	7.7	94	26	5.2	0	1	0.5	14.6	115	151	919	7	5	0.35	0.26	2	12.5
M. Medvezhye		198	7.8	95	29	4.7	0.01	1	0.35	22.1	586	317	230	9	1	0.19	0.26	2.1	11.0
Nevidim		59	8.1	40	22	2.5	0.25	2	1.32	42.8	138	517	1457	19	5	0.12	0.27	3.4	12.5
Shamelya		96	8.2	27	12	3.7	0.15	2	0.46	5.4	15	283	263	14	2	0.14	0.26	3.6	24.1
N.-Georgievskoye		100	8.8	31	11	3.6	0.3	2	4.09	25.2	20	63		43	6	0	0.27	6	14.9
Cherdynskoye		200	8.4	72	16	5.9	0	1	0.22	25.5	28	34		13	2	0	0.26	7.5	27.0
Trebushinoye		94	8.3	30	13	2.9	0.32	3	0.33	33.7	26	40	1980	19	8	0	0.26	4.8	29.5
Sobachye		157	9.2	49	46	1.5	0	1	0.07	4.5	5	44	1364	5	4	0	0.27	2.8	34.0
B. Kureynoye		127	8.4	49	15	4.5	0.05	2	0.22	6.3	19	25	1233	21	8	1.3	0.26	5.5	16.1
Gashkovo		78	8.3	38	10	5.1	0.62	3	1.38	13.7	39	447	127	10	2	0	0.25	4.1	

Appendix 37 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Vishnyakovskoye		112	8.2	45	28	2.5	0.08	1	0.33	7.6	187	365	2555	26	4	0.39	0.26	3.5	30.5
Aktoban		89	8.3	41	12	4.6	0.03	1	0.04	21	40	69	268	12	6	0	0.29	3.3	30.3
Filatovo		152	7.9	64	12	7.3	0	1	0.53	13.5	478	442	680	4	25	0	0.27	3.3	12.0
Setovo		58	8.6	26	8	4.4	3.56	4	0.14	1.2	3.5	17	908	4	5	0	0.25	6.6	9.1
Borki		61	9.1	21	14	2.1	1.49	3	0.03	8.9	5.7	96	396	46	9	0	0.25	3.5	
Umreshevo		96	7.9	42	17	3.2	1.01	4	0.11	6.6	8	735	263	4	15	0		2.9	
Voskresenskoye		67	8.2	34	5	9	0.51	4	0.29	2.9	7	48	2063	20	3	0	0.26	5.7	24.7
Tibizkol		74	8.5	35	11	4.5	1.63	5	0.02	7.3	6	182	268	16	7	0	0.26	3.5	
Lavrusheno		59	8.1	33	4	10.5	0.67	5	0.03	9.4	9	25	78	7	12	0	0.25	2.7	
Aslykul		69	7.8	35	10	4.8	0.04	2	0.02	4.8	32	61	171	22	4	0	0.25	4	
Tauzatkul		49	8.3	26	7	4.8	1.24	3	1.55	0.04	0.01	3	135	0	0	0		5	
Soleniy Kulat		85	8.1	49	5	12.8	0.26	2	0.7	181	132	303	876	12	19	2	0.26	3.3	22.3
Oktyabrskoye		65	8.2	32	11	3.9	0.06	4	0.72	2	21	26	187	2	0	0.45		3.4	
Solenoye 18		97	8	41	8	6.6	0.01	2	0.02	6.5	45	2		0	0	0			17.8
Ulzhay		109	8.3	51	14	4.9	0.13	2	0.09	21.7	76	6	873	34	0	0	0.24	3.8	49.0
Ebeyty		288	8.1	80	59	4.1	0	1	0.39	7.8	22	138	158	17	7	0.1	0.26	3.3	
B. Medvezhye	2002	167	8	84	22	5.2	0.02	1	0.23	24.7	24	297	7165	11	2	0	0.26	2.6	13.4
M. Medvezhye		175	8.1	87	22	5.3	0	1	1.53	15.9	16	461	5881	8	2	0	0.26	2.7	10.1
Nevidim		68	8.4	26	12	2.8	0.52	3	1.7	3.7	27	403	2526	11	4	0	0.26	3.5	13.4
Shamelya		61	8.5	27	11	3.3	2.83	4		4	17	81	1227	9	14	0	0.25	4.2	15.5
N.-Georgievskoye		65	9	24	6	5.2	0.57	2		7.6	14	71	128	14	3	0	0.26	2.9	29.0
Cherdynskoye		115	8.6	41	7	7.8	0	1		50	33	52	1889	0	0	0	0.26	2.4	23.0
Trebushinoye		50	8	19	5	7	2.13	2		2.5	19	78	640	20	3	0	0.25	3.7	16.1
Sobachye		77	8.7	26	20	1.7	0.57	2		0.1	0.4	3	315	0	41	0		3.8	25.8
B. Kureynoye		55	8.4	25	7	5.2	0.41	2		7.7	23	36	133	11	16	0	0.26	2.8	22.7
Gashkovo		53	8.3	19	6	4.9	0.83	2		2.1	24	63	109	34	0	0	0.24	4	12.9
Vishnyakovskoye		68	8.4	29	11	4.1	0.97	2		12	71	86	403	8	9	0	0.26	3.5	26.8
Aktoban		60	8.6	29	6	6.4	3.23	4		21.6	36	14	1439	52	9	0	0.28	4.6	17.5
Filatovo		66	8.1	28	4	10	7.37	3		5.2	11	10	871	0	16	0	0.26	2.4	34.3
Setovo		37	8.8	14	7	2.9	1.98	5		0.6	4.2	3	315	0	62	0	0.25	5.6	41.0
Borki		47	9.2	15	10	2	9.53	4		0.2	1.8	5	26	19	0	0	0.24	3	
Umreshevo		49	7.8	15	6	3	8.74	3		1	4.6	7	53	0	0	0	0.25		
Voskresenskoye		43	8.3	25	3	14.3	2.44	3		2.8	4	24	2620	75	0	0	0.25	6	28.8
Lavrusheno		48	7.8	28	1	27.3	1.27	4		5.4	19	24	149	0	33	0	0.24	3.3	
Aslykul		40	8	19	6	4.5	1.08	2		14.8	385	6	879	9	18	4.4	0.24	2.8	
Tauzatkul		30	7.6	16	1	15	23	6		8.7	5.4	2	66	0	52	0	0.25	4.6	
Soleniy Kulat		66	7.6	39	3	19.7	0.28	3		10.4	21	124	64	7	30	0	0.25	3	75.0
Oktyabrskoye		41	8.6	18	6	4.2	8.28	4		0.1	1.5	0	66	12	8	0		3	
Solenoye 18		88	8.3	44	9	6.8	0.2	2		5.5	6.4	4	984	2	11	0	0.24	1.6	60.7
Ulzhay		89	8.5	43	10	5.7	0.06	3	0.36	16.8	22	37	148	19	7	0	0.25	3.3	16.9
Ebeyty		193	8.1	65	60	1.8	0.01	1	0.18	21.5	16	197	526	23	6	0	0.25	4.3	
B. Medvezhye	2003	165	7.9	77	21	4.9	0	1	0.12	6.3	12	99	603	21	4	0	0.25	5.1	29.4
M. Medvezhye		156	8.1	76	21	4.9	0	1	0.05	11.1	44	275	688	15	4	0.13	0.25	5.1	19.0
Nevidim		66	8.2	28	14	2.7	2.09	3	0.16	6.5	7.3	80	101	0	0	0	0.27	4.8	29.4
N.-Georgievskoye		68	8.6	32	9	5	0.41	3		5.7	4.2	55	465	23	2	0	0.27	4.5	9.6
Cherdynskoye		117	8.5	60	10	10.8	0.04	1		34.1	79	20	327	9	0	0	0.25	2.9	0.0
Trebushinoye		38	8.2	15	4	8.4	18	4		0.02	1	6	386	0	0	0	0.26	10	
B. Kureynoye		45	8.1	23	6	7.7	2.12	3		6	5.3	68	144	11	3	0	0.25	4.9	
Vishnyakovskoye		83	8	36	19	2.7	0.71	2		18	42	560	1022	24	3	0.66	0.25	5.6	14.2
Aktoban		57	8.4	24	6	5.2	17	3		2.9	9	2	127	0	0	0			27.4
Filatovo		50	7.1	32	2	0	3.09	3		0	0	0	193	0	0	0			
Tibizkol		59	8.4	29	10		0.2	2		4.7	3.5	44	3	17	1	0		2.2	
Soleniy Kulat		54	7.4	30	1	28.1	0.3	2		6.4	5.8	26	1215	15	10	0	0.26	6	
Ulzhay		92	8.4	42	11	5.1	0.06	2	1.68	51.5	42	15	204	11	5	0	0.25	3.5	23.0
Ebeyty		154	8.2	43	57	1.3	0	1	0.15	10.8	9	83	996	12	2	0	0.25	3.5	38.6
B. Medvezhye	2004	195	7.8	101	25	5.6	0	1	16.1	7.8	32	74	126	29	4	0.85	0.26	5.4	28.5
M. Medvezhye		194	7.8	101	24	5.9	0	1	11.1	4.8	27	193	548	25	6	0	0.26	5.8	30.9
Nevidim		79	8.3	34	17	2.7	3.3	3	4.51	7.7	63	93	1341	27	3	0	0.26	4.7	28.5
N.-Georgievskoye		95	8.7	47	14	4.7	0.25	3	0.56	1.2	1	12	0	7	0	0	0.26	3	26.5
Cherdynskoye		254	7.8	141	25	7.7	0	1	1.29	3.2	10	1	32	25	2	0	0.26	4.3	12.0
Trebushinoye		49	8.5	29	9	4.5	0.14	3	1.34	0.4	0.5	2	95	12	0	0	0.25	1.8	
B. Kureynoye		65	8.2	35	9	5.5	0.08	3	0.52	5.2	12	4	1392	20	6	0	0.26	2.3	
Vishnyakovskoye		102	8.2	41	22	2.9	0.73	3	1.68	53.9	960	49	1154	15	7	0	0.26	3.3	25.7
Aktoban		152	7.8	83	19	5.9	0.02	2	0.68	25.4	12	46	238	22	0	0	0.25	3.3	22.6
Soleniy Kulat		62	8	50	3	26.5	0.05	3	16.6	0.3	0.2	7	175	3	12	0	0.25	3.9	
Ulzhay		105	8.3	55	14	5.2	0	1	0.08	4.6	9	9	180	8	0	0	0.25	2.3	7.0
Ebeyty		172	8.2	48	62	1.2	0	1	7.98	6.3	29	18	498	11	1	0	0.26	2.8	
Tus		73	8.2	22	34	0.9	0.01	2	0.75	37.8	27	91	107	20	1	0	0.26	2.2	
Svatikovo		155	7.7	96	16	7.8	0	1	2.14	3.1	13	16	1392	37	2	0	0.24	6.6	
min	1995–2004	30	7.1	14	1	0	0	1	0.01	0	0	0	0	0	0	0	0.21	1.6	0.0
max		288	9.2	141	92	94.5	23	6	16.6	181	960	801	7165	75	62	4.4	0.29	12	75.0
M		112	8.2	53	17	8.69	1.43	2	1.42	22.2	48.4	131	711.8	14	5.1	0.13	0.25	4.2	22.3
σ		56.6	0.4	28	16	12	3.65	1	3.03	29.8	117	162	1100	12	8.8	0.43	0.01	1.6	11.2
C_v, %		50.5	4.5	52	92	138	255	47	213	134	243	123	154.5	84	172	339	4.72	38	50.2

Note. Designations 1–15 are given in App. 36, 16 — diameter of cysts, 17 — weight of shrimp, 18 — *F* (sum of cysts, eggs, nauplii in recalculation on brood).

Appendix 38. **Correlation matrix between average statistical values of abiotic and biotic parameters of Artemia lakes on all season data ($n = 144$)**

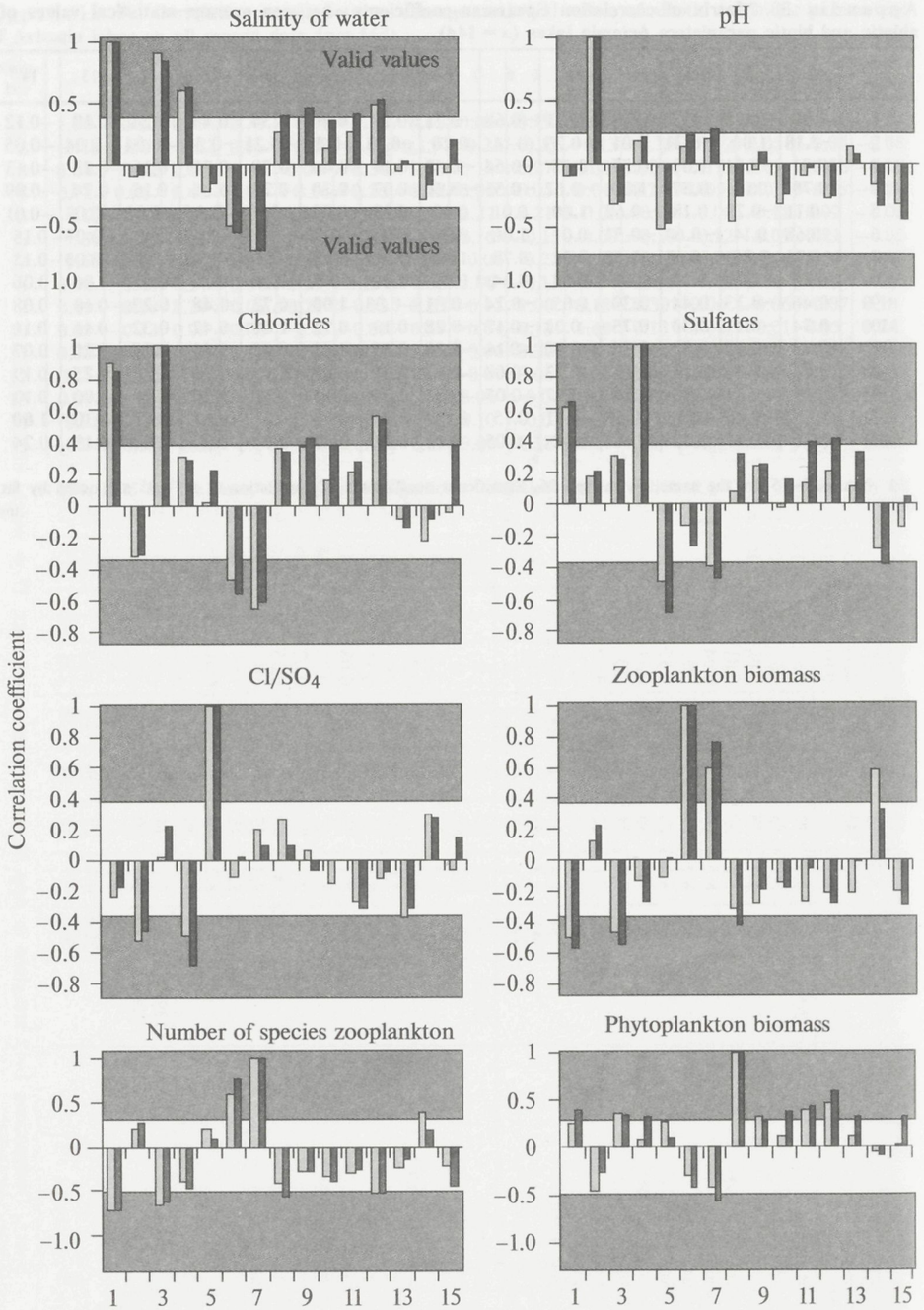
Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**1.00**	**−0.18**	**0.89**	**0.71**	−0.16	**−0.36**	**−0.65**	0.06	**0.19**	0.09	**0.28**	0.15	0.07	**−0.25**	−0.04
2	**−0.18**	**1.00**	**−0.32**	0.06	**−0.19**	−0.06	0.15	**−0.25**	**−0.19**	−0.13	**−0.27**	−0.02	0.05	−0.04	−0.08
3	**0.89**	**−0.32**	**1.00**	**0.40**	0.00	**−0.34**	**−0.58**	0.14	**0.27**	0.08	**0.26**	0.15	0.09	**−0.26**	−0.03
4	**0.71**	0.06	**0.40**	**1.00**	**−0.36**	**−0.25**	**−0.42**	0.00	0.05	0.04	**0.20**	0.05	0.03	−0.16	−0.04
5	−0.16	**−0.19**	0.00	**−0.36**	**1.00**	0.10	0.12	**0.27**	**0.21**	−0.01	−0.04	−0.02	−0.11	0.02	−0.02
6	**−0.36**	−0.06	**−0.34**	**−0.25**	0.10	**1.00**	**0.49**	0.16	−0.15	−0.09	**−0.18**	−0.12	−0.09	**0.21**	−0.05
7	**−0.65**	0.15	**−0.58**	**−0.42**	0.12	**0.49**	**1.00**	−0.06	**−0.23**	−0.10	**−0.19**	−0.15	0.00	**0.31**	−0.08
8	0.06	**−0.25**	0.14	0.00	**0.27**	0.16	−0.06	**1.00**	−0.12	−0.04	−0.06	−0.09	0.06	0.10	0.08
9	**0.19**	**−0.19**	**0.27**	0.05	**0.21**	−0.15	**−0.23**	−0.12	**1.00**	**0.18**	**0.30**	0.06	−0.06	−0.07	**0.18**
10	0.09	−0.13	0.08	0.04	−0.01	−0.09	−0.10	−0.04	**0.18**	**1.00**	0.13	0.06	−0.01	0.05	**0.24**
11	**0.28**	**−0.27**	**0.26**	**0.20**	−0.04	**−0.18**	**−0.19**	−0.06	**0.30**	0.13	**1.00**	**0.27**	0.02	−0.06	0.04
12	0.15	−0.02	0.15	0.05	−0.02	−0.12	−0.15	−0.09	0.06	0.06	**0.27**	**1.00**	0.15	−0.10	0.02
13	0.07	0.05	0.09	0.03	−0.11	−0.09	0.00	0.06	−0.06	−0.01	0.02	0.15	**1.00**	**−0.18**	0.01
14	**−0.25**	−0.04	**−0.26**	−0.16	0.02	**0.21**	**0.31**	0.10	−0.07	0.05	−0.06	−0.10	**−0.18**	**1.00**	0.13
15	−0.04	−0.08	−0.03	−0.04	−0.02	−0.05	−0.08	0.08	**0.18**	**0.24**	0.04	0.02	0.01	0.13	**1.00**

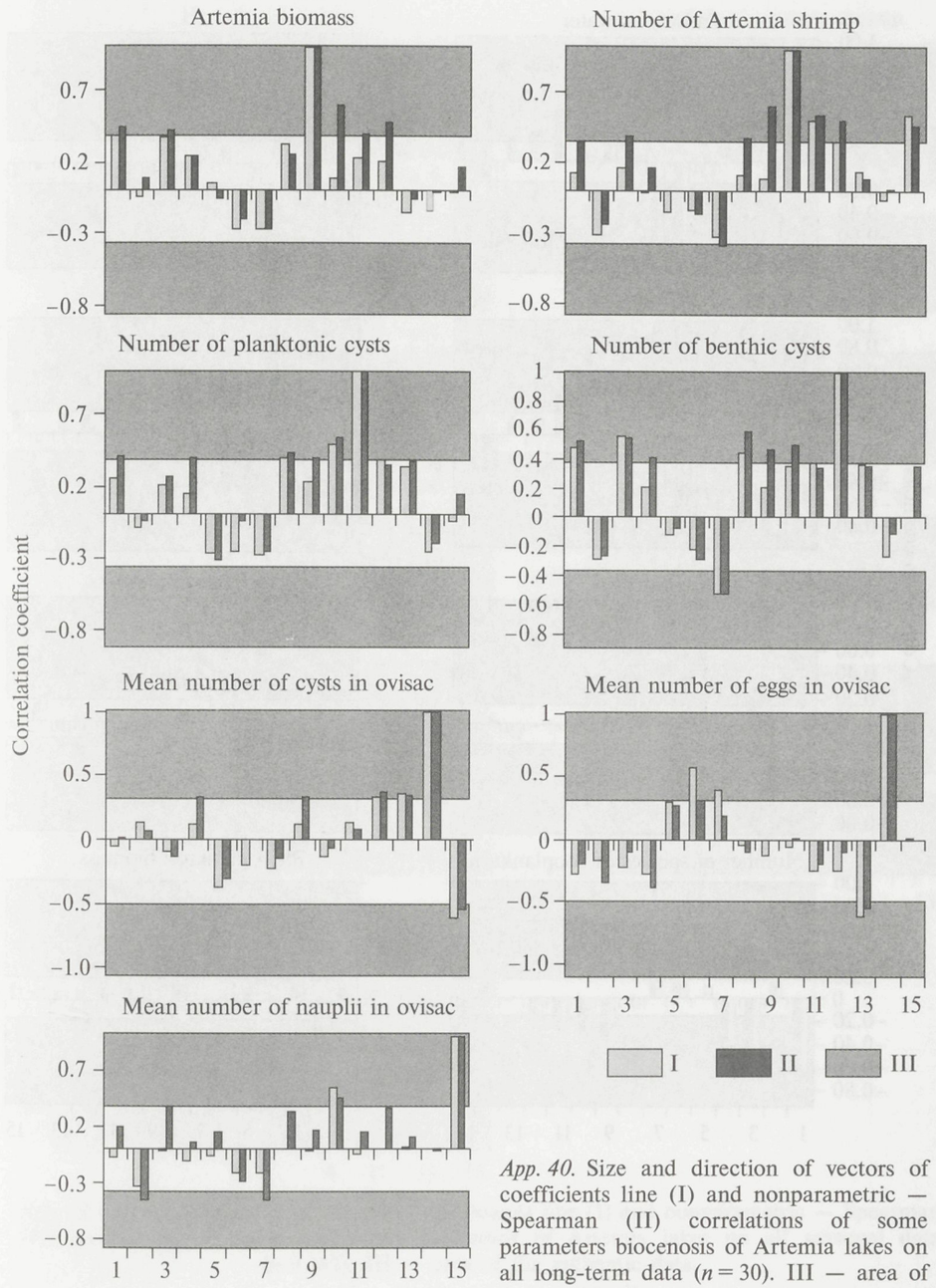
Note. 1–15 are the same, as in App. 36. Significant coefficients of correlation at $p < 0.05$ are noted by fat font.

Appendix 39. **Matrix of correlation Spearman-coefficients between average statistical values of abiotic and biotic parameters Artemia lakes ($n = 144$)**

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**1.00**	**−0.18**	**0.91**	**0.78**	−0.11	**−0.68**	**−0.71**	0.12	**0.46**	**0.34**	**0.43**	**0.24**	**0.19**	−0.12
2	**−0.18**	**1.00**	**−0.31**	0.01	**−0.29**	0.14	**0.20**	**−0.31**	**−0.23**	**−0.21**	**−0.30**	−0.04	−0.04	−0.05
3	**0.91**	**−0.31**	**1.00**	**0.57**	**0.18**	**−0.64**	**−0.62**	0.14	**0.44**	**0.30**	**0.39**	0.16	**0.18**	−0.13
4	**0.78**	0.01	**0.57**	**1.00**	**−0.62**	**−0.51**	**−0.50**	0.07	**0.30**	**0.25**	**0.36**	0.16	**0.24**	−0.09
5	−0.11	**−0.29**	**0.18**	**−0.62**	**1.00**	0.01	0.02	0.08	0.05	−0.03	−0.04	−0.03	−0.07	−0.01
6	**−0.68**	0.14	**−0.64**	**−0.51**	0.01	**1.00**	**0.78**	0.04	**−0.24**	**−0.17**	−0.14	−0.08	−0.07	0.15
7	**−0.71**	**0.20**	**−0.62**	**−0.50**	0.02	**0.78**	**1.00**	0.00	**−0.31**	**−0.28**	**−0.28**	−0.15	−0.03	0.13
8	0.12	**−0.31**	0.14	0.07	0.08	0.04	0.00	**1.00**	−0.03	0.10	0.16	0.07	0.06	0.06
9	**0.46**	**−0.23**	**0.44**	**0.30**	0.05	**−0.24**	**−0.31**	−0.03	**1.00**	**0.72**	**0.48**	**0.23**	0.10	0.08
10	**0.34**	**−0.21**	**0.30**	**0.25**	−0.03	**−0.17**	**−0.28**	0.10	**0.72**	**1.00**	**0.42**	**0.32**	0.11	0.11
11	**0.43**	**−0.30**	**0.39**	**0.36**	−0.04	−0.14	**−0.28**	0.16	**0.48**	**0.42**	**1.00**	**0.25**	**0.20**	0.07
12	**0.24**	−0.04	0.16	0.16	−0.03	−0.08	−0.15	0.07	0.07	**0.23**	**0.32**	**1.00**	**0.25**	0.19
13	**0.19**	−0.04	**0.18**	**0.24**	−0.07	−0.07	−0.03	0.06	0.10	0.11	**0.20**	0.16	**1.00**	0.10
14	−0.12	−0.05	−0.13	−0.09	−0.01	0.15	0.13	0.06	0.08	0.11	0.07	0.16	0.10	**1.00**
15	**0.26**	−0.11	**0.32**	**0.18**	0.02	−0.05	−0.12	0.12	**0.32**	**0.34**	**0.33**	0.02	**0.19**	0.24

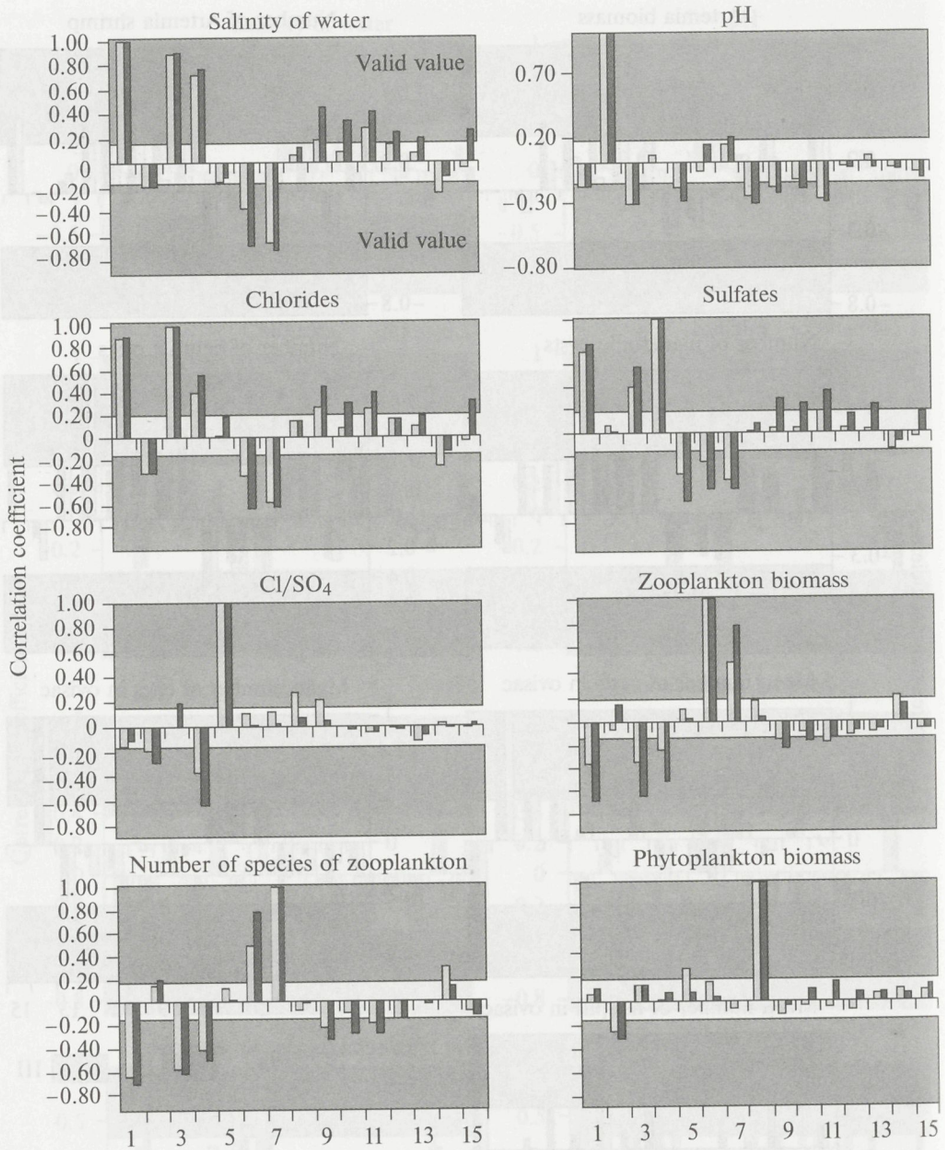
Note. 1–15 are the same, as in App. 36. Significant coefficients of correlation at $p < 0.05$ are noted by fat font.

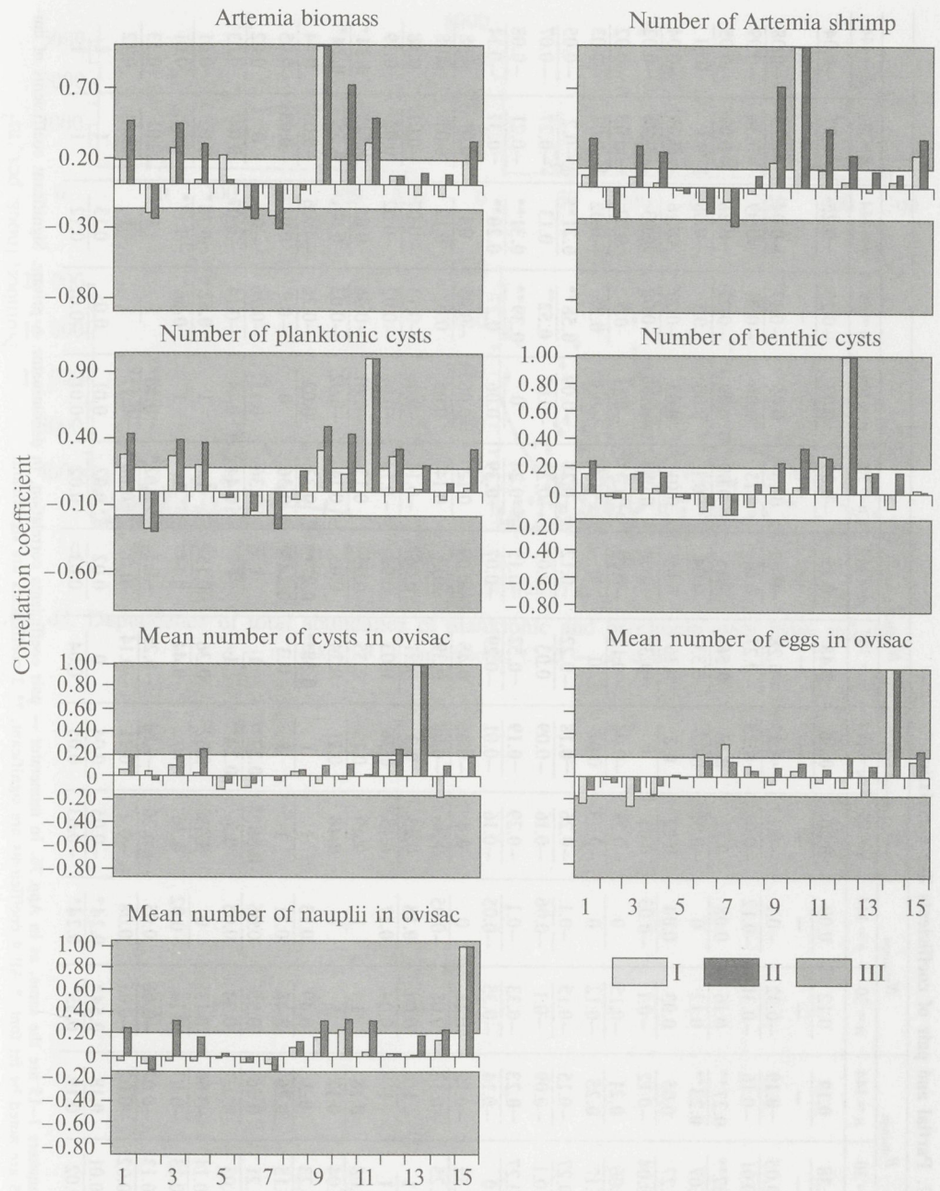




App. 40. Size and direction of vectors of coefficients line (I) and nonparametric — Spearman (II) correlations of some parameters biocenosis of Artemia lakes on all long-term data ($n = 30$). III — area of the authentic data.

1–15 — are the same, as in App. 36.





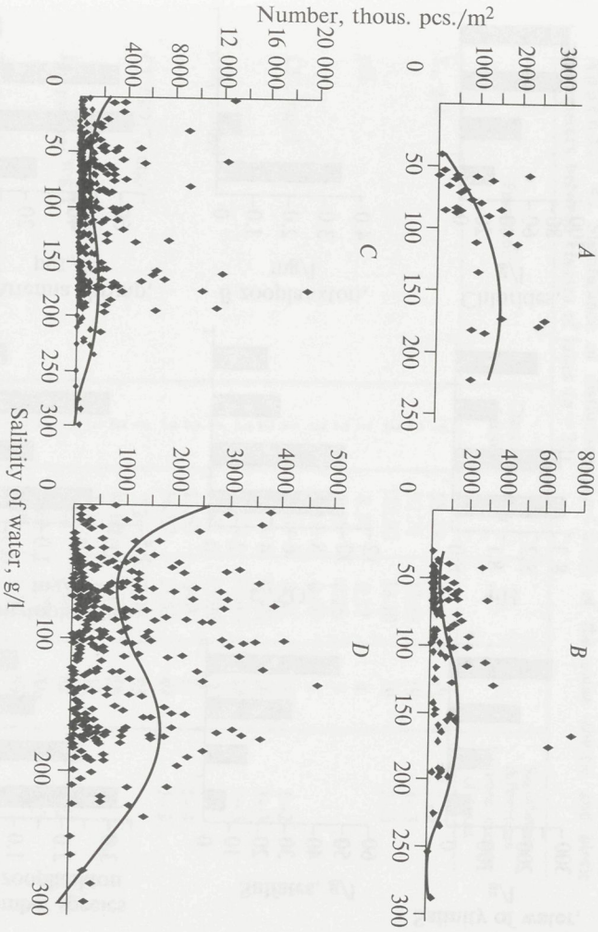
App. 41. Size and direction of vectors of coefficients line (I) and nonparametric — Spearman (II) correlations of some parameters biocenosis of Artemia lakes on all seasonal data ($n = 142$). III — area of the authentic data.

1–15 — are the same, as in App. 36.

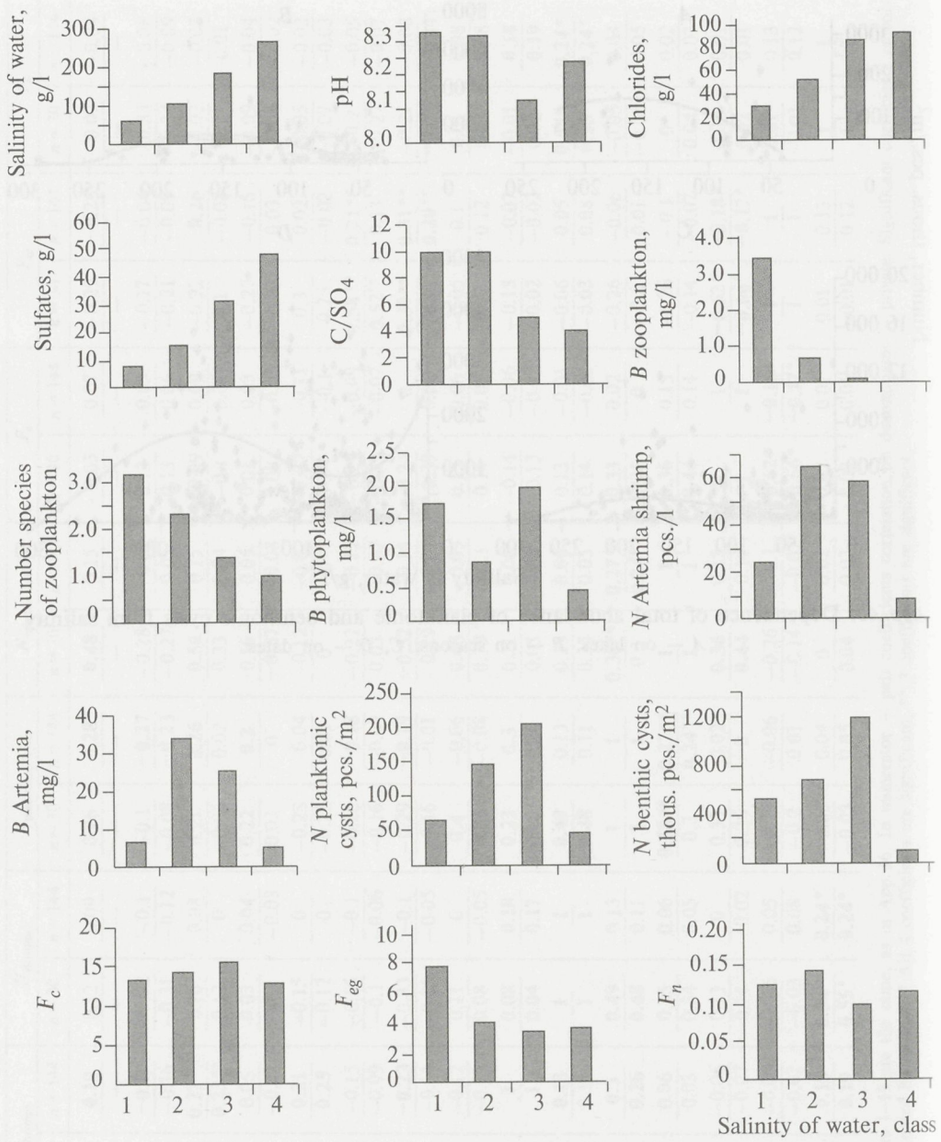
Appendix 42. **Partial and pair of coefficients line correlation**

Parameter	$B_{shrimps}$		$N_{shrimps}$		$N_{planktonic\ cysts}$		$N_{benthic\ cysts}$		F_c		F_{eg}		F_n	
	$n=30$	$n=144$	$n=30$	$n=144$	$n=30$	$n=144$	$n=30$	$n=144$	$n=30$	$n=144$	$n=30$	$n=144$	$n=30$	$n=144$
1	**0.38** / —	**0.19** / —	0.12 / —	0.09 / —	0.26 / —	**0.28** / —	**0.48** / —	0.15 / —	−0.05 / —	0.07 / —	−0.29 / —	**−0.25** / —	−0.07 / —	−0.04 / —
2	−0.05 / −0.01	**−0.19** / −0.16	−0.32 / −0.31	−0.1 / −0.12	−0.1 / −0.08	**−0.27** / **−0.23**	−0.28 / −0.27	−0.02 / 0.01	0.13 / 0.13	0.05 / 0.06	−0.17 / −0.21	−0.04 / −0.09	−0.33 / −0.34	−0.08 / −0.09
3	**0.37**** / 0.07	**0.27**** / **0.23****	0.16 / 0.12	0.08 / 0	0.21 / −0.06	**0.26** / 0.02	**0.56** / 0.33	0.15 / 0.04	−0.09 / −0.1	0.09 / 0.06	−0.22 / 0.1	**−0.26** / −0.08	−0.02 / 0.1	−0.03 / 0.01
4	0.27 / −0.04	0.05 / −0.12	0.03 / −0.1	0.04 / −0.03	0.22 / 0.03	**0.2** / 0	0.16 / **−0.37**	0.05 / −0.08	0.01 / 0.08	0.03 / −0.03	−0.27 / −0.08	−0.16 / 0.03	−0.09 / −0.06	−0.04 / −0.02
5	0.06 / 0.17	**0.21** / **0.25**	−0.15 / −0.12	0 / 0	−0.28 / −0.23	−0.04 / 0.01	−0.12 / 0	−0.02 / 0	**−0.37** / **−0.4**	−0.11 / −0.1	0.3 / 0.25	0.02 / −0.02	−0.05 / −0.07	−0.02 / −0.03
6	−0.27 / −0.1	−0.15 / −0.09	−0.15 / −0.1	−0.1 / −0.06	−0.26 / −0.16	**−0.18** / −0.09	−0.22 / 0.03	−0.12 / −0.07	−0.21 / −0.27	−0.09 / −0.07	**0.58**** / **0.52****	**0.21**** / 0.13	−0.2 / −0.27	−0.05 / −0.07
7	−0.27 / 0	**−0.23** / −0.14	−0.33 / −0.35	−0.1 / −0.05	−0.29 / −0.16	**−0.19** / −0.01	**−0.52** / −0.29	−0.15 / −0.07	−0.24 / **−0.39**	0 / 0.06	**0.39**** / 0.27	**0.31**** / **0.20****	−0.21 / **−0.37**	−0.08 / −0.14
8	0.32 / 0.25	−0.12 / −0.13	0.11 / 0.08	0 / −0.05	**0.4** / **0.36**	−0.06 / −0.08	**0.45** / **0.39**	−0.09 / −0.1	0.12 / 0.14	0.06 / 0.06	−0.05 / 0.02	0.1 / 0.12	0.01 / 0.03	0.08 / 0.08
9	**1** / **1**	**1** / **1**	0.08 / 0.04	**0.18** / **0.17**	0.23 / 0.15	**0.3** / **0.26**	0.21 / 0.03	0.06 / 0.03	−0.14 / −0.13	−0.06 / −0.07	−0.13 / −0.02	−0.07 / −0.02	−0.01 / 0.02	**0.18** / **0.19**
10	0.08 / 0.04	**0.18** / **0.17**	**1** / **1**	**1** / **1**	**0.49** / **0.48**	0.13 / 0.11	0.35 / 0.34	0.06 / 0.05	0.13 / 0.14	−0.01 / −0.02	−0.06 / −0.03	0.05 / 0.08	**0.54*** / **0.55***	**0.24*** / **0.24***
11	0.23 / 0.15	**0.3** / **0.26**	**0.49** / **0.48**	0.13 / 0.11	**1** / **1**	**1** / **1**	**0.38**** / 0.3	**0.27**** / **0.24****	0.33 / **0.36**	0.02 / 0	−0.26 / −0.2	−0.06 / 0.01	−0.05 / −0.03	0.04 / 0.05
12	0.21 / 0.03	0.06 / 0.03	0.35 / 0.34	0.06 / 0.05	**0.38**** / 0.3	**0.27**** / **0.24****	**1** / **1**	**1** / **1**	**0.36** / **0.44**	0.15 / 0.14	−0.26 / −0.14	−0.1 / −0.07	0 / 0.04	0.02 / 0.03
13	−0.14 / −0.13	−0.06 / −0.07	0.13 / 0.14	0 / −0.02	0.33 / **0.36**	0.02 / 0	**0.36** / **0.44**	0.15 / 0.14	1 / **1**	1 / **1**	**−0.62*** / **−0.66***	**−0.18*** / **−0.17***	0.02 / 0.02	0.01 / 0.01
14	−0.13 / −0.02	−0.07 / −0.02	−0.06 / −0.03	0.05 / 0.08	−0.26 / −0.2	−0.06 / 0.01	−0.26 / −0.14	−0.1 / −0.07	**−0.62*** / **−0.66***	**−0.18*** / **−0.17***	**1** / **1**	**1** / 1	0.01 / −0.01	0.13 / 0.12
15	−0.01 / 0.02	**0.18** / **0.19**	**0.54*** / **0.55***	**0.24*** / **0.24***	−0.05 / −0.03	0.04 / 0.05	0 / 0.04	0.02 / 0.03	0.02 / 0.02	0.01 / 0.01	0.01 / −0.01	0.13 / 0.12	**1** / 1	**1** / **1**

Note. Parameters 1–15 are the same, as in App. 36. In numerator — pair coefficients correlation, in denominator — private. Significant coefficients of correlation at $p < 0.05$ are noted by fat font. * All 4 coefficients are significant, ** 3 coefficients are significant.



App. 43. Dependence of total abundance of planktonic and benthonic cysts from salinity. *A* — on lakes; *B* — on seasons; *C*, *D* — on dates.



App. 44. Average statistical indicators of biotic and abiotic parameters of biocenosis of Artemia lakes ($n = 144$).

Appendix 45. **Significance of distinctions ($p < 0.05$) of the some abiotic and biotic parameters between classes of lakes ($n = 30$)**

Parameter	Classes of lakes	M	σ	C_v	Significant differences between classes of lakes
Σ_i, g/l	1	58.33	7.59	13	1–2
	2	92.76	17.23	19	1–3
	3	185.92	18.10	10	2–3
pH	1	8.37	0.37	4	
	2	8.18	0.26	3	
	3	8.16	0.40	5	
Cl^-, mg/l	1	29.07	4.53	16	1–2
	2	46.71	12.01	26	1–3
	3	83.27	15.46	19	2–3
SO_4^{2-}, mg/l	1	13.01	15.96	123	
	2	13.53	9.61	71	1–3
	3	36.07	17.52	49	2–3
Cl^-/SO_4^{2-}, mg/l	1	7.24	3.99	55	
	2	10.60	8.46	80	
	3	5.44	1.83	34	
$B_{zooplankton}$, mg/l	1	2.98	2.63	88	1–2
	2	1.20	1.28	106	1–3
	3	0.09	0.08	89	
The number of zooplankton, pcs.	1	3.17	0.60	19	1–2
	2	2.43	0.77	32	1–3
	3	1.42	0.47	33	2–3
$B_{phytoplankton}$, mg/l	1	0.52	0.85	164	
	2	1.10	1.53	139	1–3
	3	1.91	1.65	87	
$B_{Artemia\ shrimps}$, mg/l	1	12.06	9.51	79	
	2	22.83	14.78	65	
	3	23.25	19.91	86	
$N_{Artemia\ shrimps}$, ind./l	1	29.85	55.48	186	
	2	48.47	62.15	128	
	3	42.47	52.13	123	
$N_{planktonic\ cysts}$, ind./l	1	50.72	47.48	94	1–2
	2	130.61	96.38	74	
	3	125.01	108.55	87	
$N_{benthic\ cysts}$, thous. ind./m²	1	587.54	673.97	115	
	2	736.60	494.66	67	1–3
	3	1424.19	695.11	49	2–3
F_c	1	16.12	9.21	57	
	2	14.59	5.14	35	
	3	14.20	5.82	41	
F_{eg}	1	9.57	15.08	158	
	2	6.28	5.12	82	
	3	4.23	2.84	67	
F_n	1	0.27	0.68	255	
	2	0.11	0.11	99	
	3	0.17	0.14	78	

Appendix 46. **Biomass of shrimps and abundance of cysts in Artemia lakes for the period of researches**

Lake; Area, km²; Water volume, million m³	Year	Salinity average April — October, g/l	Biomass of shrimps, mg/l					Cyst density June — October		Stocks of raw cysts in autumn			
			average April — October	max per season	max for the 1st generation (May — June)	max for the 2nd generation (July)	max for 3rd generation (August — September)	Planktonic cysts, thous. ind./m³	Benthic cysts, thous. ind./m²	total		without benthic cysts	
										g/m³	g/m²	g/m³	g/m²
			X_1	X_2	X_3	X_4	X_5	X_6	X_7	Y_1	Y_2	Y_3	Y_4
M. Medvezhye; 18.1; 12.2	2000	235	9	23.3	14	0.6	23.3	414	248	13.5	6.7	2.9	1.4
	2001	198	22.1	163.9	163.9	25.5	7.5	317	230	9.5	6.6	5.5	3.8
	2002	175	15.9	88	88	20.3	26	461	5881	60	54	7.4	6.6
	2003	156	11.1	42.1	42.1	4.8	5.1	275	688	30.9	21.7	3.8	2.7
B. Medvezhye; 38.3; 25.8	2000	225	9.8	53.3	4.9	0.9	53.3	136	220	16	17	8.9	9.4
	2001	198	14.6	116.2	116.2	15.5	5.8	151	919	11.2	7.9	5.3	3.7
	2002	167	24.7	62.2	53.5	40.4	62.2	297	7165	72.4	65.2	10	9
	2003	165	6.3	36.7	36.7	5.6	2.5	99	603	35.8	25.1	1.1	0.8
Nevidim; 7.2; 5.5	2001	101	42.8	253.9	56.4	253.9	1.6	517	1457	48.9	34.2	6.8	4.7
	2002	68	3.7	8.2	8.2	7.6	1.8	403	2526	33.2	26.3	19.3	15.3
	2003	66	6.5	41.1	41.1	4.9	0.7	80	101	4	3.2	1.5	1.2
Vishnyakovskoye; 2.1; 1.9	2001	112	7.6	22.8	19.6	22.8	2.6	365	2555	23.6	18.9	14.6	11.7
	2002	68	12	38.1	38.1	5.1	0.5	86	403	5.3	4.8	0.2	0.2
	2003	83	18	43.15	43.15	30	16.6	560	1022	27.1	24.4	23	20.7
Cherdynskoye; 1.6; 1.8	2001	200	25.5	59.4	59.4	35	10.4	34	1994	24.6	27	2.8	3.1
	2003	117	34.1	84.7	84.7	27.7	1	20	327	5.4	5.9	0.06	0.1
N.-Georgievskoye; 2; 2	2002	65	7.6	41.6	16.3	41.6	10.2	71	128	4.7	4.7	1.5	1.5
	2003	68	5.7	10.6	10.6	7	3.8	55	465	3.2	3.2	0.6	0.6
Filatovo; 23.7; 11.8	2001	152	13.5	22.1	12.9	7	1	442	680	5.9	3	2.3	1.1
	2002	66	5.2	18.1	18.1	9	0.1	10	871	3.2	1.6	0.3	0.2
B. Kureynoye; 3.7; 3.2	2001	127	6.3	13.4	13.4	8	1.9	25	1233	12.3	7.6	4.8	3
	2002	55	7.7	14.7	14.7	14.1	5.2	36	133	3.6	3.6	0.8	0.8
	2003	45	6	19.9	19.9	13	4.8	68	144	2.8	2.8	0.7	0.7
Trebushinoye; 3.1; 2.7	2001	94	33.7	89.8	89.8	50	11.5	40	1980	54.5	43.5	4.1	3.2
	2002	50	2.5	88.4	12.7	88.4	6	78	640	40.1	36	2.3	2.1
	2003	38	0.02	0.2	0.1	0.2	0.2	6	386	7.6	6.9	0.1	0.1
Ebeyty; 83.3; 33.3	2001	288	7.8	24.9	24.9	4.1	—	138	158	6.3	2.5	1	0.4
	2002	193	21.5	56.9	5.6	56.9	46.7	197	526	13.6	5.4	4.2	1.7
	2003	154	10.8	36.3	9	36.3	9.5	83	996	14.3	5.7	0.4	0.2
Aktoban; 6.6; 4.3	2001	89	21	69.3	69.3	37	3.7	69	268	16.9	10.1	11.3	6.8
	2002	60	21.6	59.1	59.1	30	0.8	14	1439	9.4	6.6	0.4	0.3
Ulzhay; 8.6; 51.5	2002	89	16.8	63.3	63.3	27.8	4.2	37	148	5.6	2.8	0.2	0.1
	2003	92	70.6	207.1	207.1	50	0.6	15	204	4.5	2.2	0.05	0.02
Gashkovo; 3.5; 3.9	2002	53	2.1	5.8	5.8	3	0.8	63	109	5.7	6.2	0.5	0.5
Soleniy Kulat; 0.5; 0.3	2003	54	6.4	12.1	9	10	12.1	26	1215	29	17.3	1	0.6

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Appendix 47. **Correlation matrix between parameters of production of Artemia populations ($p < 0.05$; $n = 35$)**

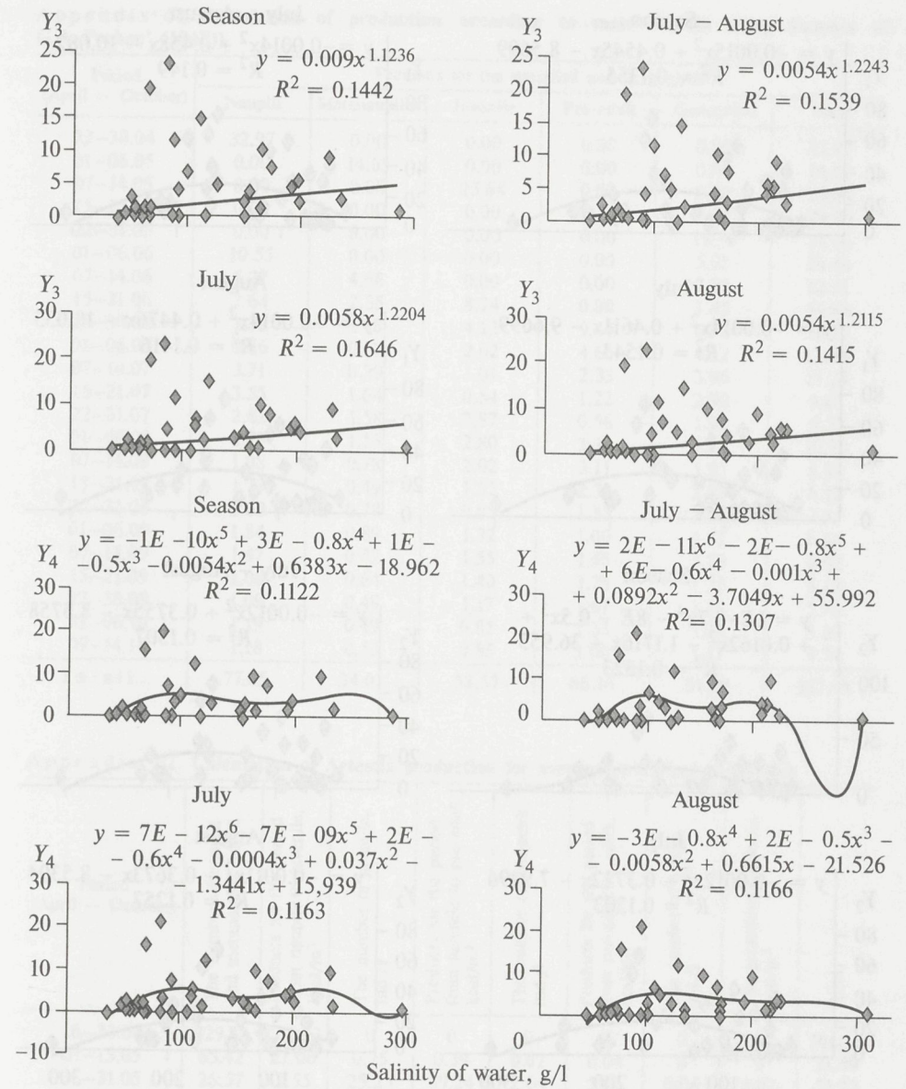
Index	X_1	X_2	X_3	X_4	X_5	X_6	X_7	Y_1	Y_2	Y_3	Y_4
X_1	**1.00**	**0.80**	**0.78**	**0.51**	−0.03	0.07	0.12	0.18	0.16	0.01	0.00
X_2	**0.80**	**1.00**	**0.76**	**0.74**	−0.07	0.22	0.07	0.27	0.24	0.04	0.01
X_3	**0.78**	**0.76**	**1.00**	0.18	−0.13	0.02	0.09	0.08	0.09	−0.01	−0.02
X_4	**0.51**	**0.74**	0.18	1.00	−0.07	0.28	0.11	**0.40**	**0.34**	0.10	0.07
X_5	−0.03	−0.07	−0.13	−0.07	**1.00**	0.16	0.27	0.22	0.23	0.12	0.15
X_6	0.07	0.22	0.02	0.28	0.16	**1.00**	**0.40**	**0.45**	**0.42**	**0.68**	**0.65**
X_7	0.12	0.07	0.09	0.11	0.27	**0.40**	**1.00**	**0.79**	**0.83**	**0.40**	**0.42**
Y_1	0.18	0.27	0.08	**0.40**	0.22	**0.45**	**0.79**	**1.00**	**0.98**	**0.44**	**0.45**
Y_2	0.16	0.24	0.09	**0.34**	0.23	**0.42**	**0.83**	**0.98**	**1.00**	**0.44**	**0.48**
Y_3	0.01	0.04	−0.01	0.10	0.12	**0.68**	**0.40**	**0.44**	**0.44**	**1.00**	**0.99**
Y_4	0.00	0.01	−0.02	0.07	0.15	**0.65**	**0.42**	**0.45**	**0.48**	**0.99**	**1.00**

Note. Significant link at 5 % level of significance is noted by fat font. Designations X_1–X_7 and Y_1–Y_4 are given in App. 46.

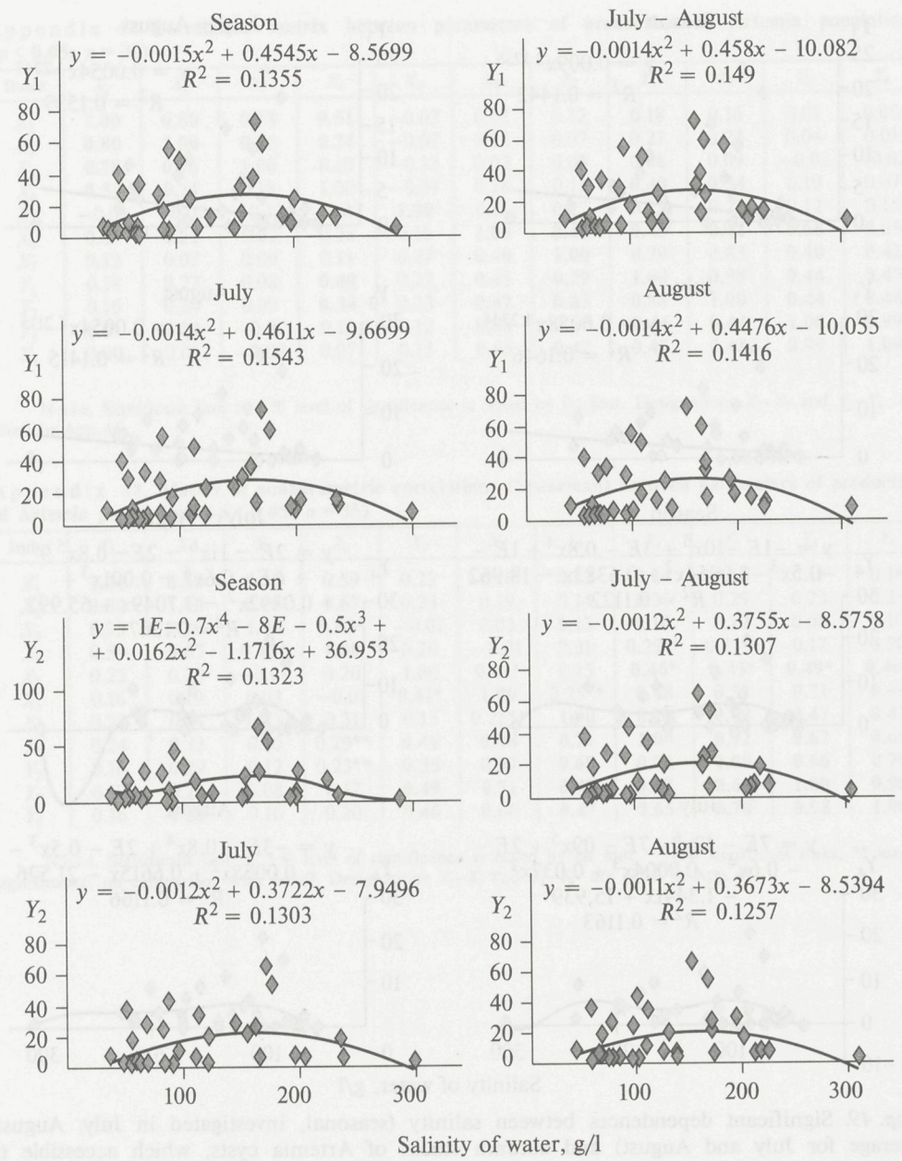
Appendix 48. **Matrix of nonparametric correlations (Spearman) between parameters of production of Artemia populations ($p < 0.05$; $n = 35$)**

Index	X_1	X_2	X_3	X_4	X_5	X_6	X_7	Y_1	Y_2	Y_3	Y_4
X_1	**1.00**	**0.80**	**0.73**	**0.59**	0.22	0.16	0.23	0.24	0.16	0.17	0.16
X_2	**0.80**	**1.00**	**0.76**	**0.67**	0.23	0.19	0.14	0.33	0.29	0.23	0.25
X_3	**0.73**	**0.76**	**1.00**	**0.43***	−0.01	0.03	0.13	0.10	0.12	0.08	0.10
X_4	**0.59**	**0.67**	**0.43***	**1.00**	0.20	−0.01	0.31	0.29**	0.23**	0.17	0.20
X_5	0.22	0.23	−0.01	0.20	**1.00**	**0.41***	0.15	**0.46***	**0.35***	**0.49***	**0.46***
X_6	0.16	0.19	0.03	−0.01	**0.41***	**1.00**	0.25**	**0.48**	**0.37**	**0.71**	**0.66**
X_7	0.23	0.14	0.13	0.31	0.15	0.25**	**1.00**	**0.71**	**0.69**	**0.47**	**0.47**
Y_1	0.24	0.33	0.10	0.29**	**0.46**	**0.48**	**0.71**	**1.00**	**0.92**	**0.67**	**0.65**
Y_2	0.16	0.29	0.12	0.23**	**0.35**	**0.37**	**0.69**	**0.92**	**1.00**	**0.66**	**0.70**
Y_3	0.17	0.23	0.08	0.17	**0.49**	**0.71**	**0.47**	**0.67**	**0.66**	**1.00**	**0.98**
Y_4	0.16	0.25	0.10	0.20	**0.46**	**0.66**	**0.47**	**0.65**	**0.70**	**0.98**	**1.00**

Note. Significant link at 5 % level of significance is noted by fat font. * New significant links; ** loss of significance, un comparison with linear. Designations X_1–X_7 and Y_1–Y_4 are given in App. 46.



App. 49. Significant dependences between salinity (seasonal, investigated in July, August, average for July and August) and autumn stocks of Artemia cysts, which accessible to catch.



App. 50. Significant dependences between salinity (seasonal, investigated in July, August, average for July and August) and autumn stocks of Artemia cysts.

Appendix 51. Calculation of production according to matrix (with using formula of G.A. Pechen' (1968))

Period (April — October)	Products for the specified period, kcal/m²					
	Nauplii	Metanauplius	Juvenile	Pre-adult	Generative	Total
22–30.04	32.97	0.00	0.00	0.00	0.00	32.97
01–06.05	0.00	14.65	0.00	0.00	0.00	14.65
07–14.05	0.00	0.00	25.64	0.00	0.00	25.64
15–21.05	0.00	0.00	0.00	29.30	0.00	29.30
22–31.05	0.00	0.00	0.00	0.00	11.76	11.76
01–06.06	10.55	0.00	0.00	0.00	5.91	16.46
07–14.06	5.27	4.68	0.00	0.00	2.95	12.91
15–21.06	2.64	2.35	8.24	0.00	1.45	14.68
22–30.06	1.32	1.18	4.12	9.44	0.72	16.77
01–06.07	0.66	0.58	2.02	4.66	4.12	12.04
07–14.07	3.71	0.29	1.01	2.33	3.96	11.29
15–21.07	3.55	1.64	0.54	1.22	2.90	9.85
22–31.07	2.62	1.58	2.87	0.56	1.95	9.57
01–06.08	1.73	1.15	2.80	3.33	1.23	10.24
07–14.08	1.08	0.78	2.02	3.11	1.95	8.93
15–21.08	1.73	0.49	1.32	2.33	2.23	8.10
22–31.08	2.00	0.78	0.85	1.55	2.06	7.25
01–06.09	1.84	0.89	1.32	1.00	1.62	6.66
07–14.09	1.47	0.82	1.55	1.55	1.23	6.62
15–21.09	1.08	0.64	1.40	1.78	1.23	6.12
22–30.09	1.09	0.49	1.17	1.67	1.34	5.74
01–06.10	1.19	0.49	0.85	1.33	1.34	5.20
07–14.10	1.18	0.53	0.85	1.00	1.17	4.74
In all...	77.65	34.01	58.59	66.16	51.09	287.49

Appendix 52. Calculation of Artemia production for average statistical population

Period (April — October)	The number of nauplii and metanauplii, ind./l	Products for the period from nauplii to juvenile, kcal/m²	The number of juvenile, ind./l	Products for the period from juvenile to pre-adult, kcal/m²	The number of pre-adult, ind./l	Products for the period from pre-adult to adult, kcal/m²	The number of adults, ind./l	The generative products, kcal/m²	Total
16–30.04	329.71	106.13	0	0	0	0	0	0	106.13
01–15.05	65.42	21.06	0.25	0.39	0.02	0.04	0	0	21.49
16–31.05	26.57	8.55	25.25	39.24	2.64	5.86	0.06	0.07	53.72
01–15.06	57.57	18.53	6.32	9.82	6.71	14.90	4.55	5.07	48.32
16–30.06	11.5	3.70	3.65	5.67	6.63	14.72	2.32	2.59	26.68
01–15.07	7.84	2.52	0.5	0.78	5.7	12.65	5.27	5.87	21.83
16–31.07	42.94	13.82	1.44	2.24	7.07	15.70	8.09	9.01	40.77
01–15.08	6.98	2.25	0.35	0.54	0.69	1.53	0.84	0.94	5.26
16–31.08	1.01	0.33	0.19	0.30	0.58	1.29	1.58	1.76	3.67
01–15.09	1.04	0.33	0.19	0.30	0.43	0.95	3.12	3.48	5.06
16–30.09	3.1	1.00	0.05	0.08	0.77	1.71	3.11	3.47	6.25
01–15.10	0.15	0.05	0.01	0.02	0.19	0.42	0.4	0.45	0.93
Total production for the season...									**340.11**

Appendix 53. **Calculation of production and *P/B*-coefficients for populations of two model lakes for the three-year period**

The period of studies	Production, kcal/(m² · day)					Production for the month, kcal/m²	Biomass, kcal/m²		*P/B* for month
	from nauplii to metanauplius	from metanauplius to juvenile	from juvenile to pre-adult	from pre-adult to adults	generative		shrimps	cysts	
1	2	3	4	5	6	7	8	9	10
Bolshoye Medvezhye									
2001:									
April	82.02	0	0	0	0	82.02	7.26	0	11.3
May	22.70	0	158.51	7.35	0.06	188.62	34.18	0	5.5
June	0.10	0	4.44	41.20	0.91	46.66	8.67	25.23	1.4
Jule	0	0	0	37.25	0.25	37.50	8.39	19.90	1.3
August	0.17	0	0	3.11	1.58	4.85	1.94	18.90	0.2
September	0	0	0	0.13	0.20	0.33	0.36	2.67	0.1
October	0	0	0	2.53	1.19	3.72	2.21	17.44	0.2
Production for the season					4.2	363.69			
The average for the season							9.71	12.56	16.3
2002:									
April	1.40	0	0	0	0	1.40	0.75	0.00	1.9
May	2.82	14.13	27.57	0.80	0	45.32	4.74	0.00	9.6
June	0	7.49	7.96	153.27	0.27	168.99	28.10	10.12	4.4
Jule	0	0	0.12	84.54	7.50	92.16	20.92	18.12	2.4
August	0	0	0	76.95	42.83	119.78	36.67	64.58	1.2
September	0	0	0	15.67	7.35	23.03	7.89	33.36	0.6
October	0	0	0	0	0.02	0.02	1.11	16.67	0.0
Production for the season					58.0	450.69			
The average for the season							16.54	22.42	11.6
2003:									
April	1.93	0	0	0	0	1.93	0.19	0.00	10.1
May	0	8.53	29.34	1.47	0	39.34	5.34	0.00	7.4
June	0	0	0	34.8984	28.97	63.87	19.57	10.86	2.1
Jule	0.54	13.31	0.92	0.07	1.61	16.46	2.04	7.93	1.7
August	0.08	1.43	1.72	0.29	0.49	4.02	1.49	9.88	0.4
September	0	0.79	3.11	0	0.58	4.48	2.00	10.56	0.4
October	0	0	0	0	0.36	0.36	1.65	19.03	0.0
Production for the season					90.0	130.45			
The average for the season							5.23	8.12	9.8
Average for 3 years					51.0	315	10.5	14.4	12.6
Maloye Medvezhye									
2001:									
April	178.42	0	0	0	0	178.42	10.26	0.00	17.4
May	3.46	0	42.49	4.26	0.11	50.32	5.39	0.00	9.3
June	6.81	0	0.87	46.09	20.10	73.87	29.43	2.28	2.3
Jule	26.31	0	12.96	176.93	70.16	286.36	145.30	75.26	1.3
August	0.39	0	0.78	0.71	0.56	2.43	0.97	7.74	0.3
September	3.08	0	0	0.22	0.80	4.10	2.29	23.97	0.2
October	0	0	0	0	0.01	0.01	1.48	22.84	0.0
Production for the season					91.7	595.52			
The average for the season							31.54	20.11	11.5

Appendix 53 (continued)

1	2	3	4	5	6	7	8	9	10
2002:									
April	2.99	0	0	0	0	2.99	1.46	0.00	2.1
May	3.30	61.41	2.86	0	0	67.58	4.27	0.00	15.8
June	0	17.02	11.16	6.84	0.10	35.12	3.30	0.39	9.5
Jule	0.15	9.32	4.27	4.51	0.84	19.09	3.12	2.99	3.1
August	0	4.74	0	0	1.404	6.15	14.57	68.46	0.1
September	0.02	0.15	0	0.09	0.29	0.55	0.51	3.18	0.1
October	0.03	0.08	0	0.01	0.19	0.31	0.45	1.94	0.1
Production for the season					2.8	131.79			
The average for the season							4.45	12.66	7.7
2003:									
April	0	0	0	0	0	0.00	0.01	0.00	0.0
May	0	4.92	29.00	0	0	33.92	2.23	0.00	15.2
June	2.83	2.37	11.66	53.15	24.16	94.16	21.43	6.12	3.4
Jule	0	0.44	0	0	1.89	2.34	3.32	1.68	0.5
August	0	0.29	0	0	0.16	0.45	1.25	12.66	0.0
September	0	1.72	0	0.13	0.27	2.12	1.16	18.21	0.1
October	0	0	0	0	0.01	0.01	0.53	3.91	0.0
Production for the season					29.3	133.00			
The average for the season							4.94	6.77	11.4
Average for 3 years					41.3	286.8	13.6	13.2	10.2

Appendix 54. **Calculation average seasonal diet and breath metabolism of Artemia shrimps**

Parameter	Nauplii	Metanauplius	Juvenile	Pre-adult	Adults	Medium daily values for Artemia populations
1	2	3	4	5	6	7
The calculation for one individual						
Individual weight, gram in wet	0.00002	0.00020	0.00060	0.00200	0.00400	
Daily diet, cal/ind.	0.018	0.093	0.202	0.473	0.771	
Energy waste for breath, cal/ind.	0.005	0.025	0.053	0.122	0.197	
Bolshoye Medvezhye						
2001						
Number for the season, ind./l	66.854	0.000	7.490	3.028	0.344	
Daily diet, cal/l	1.230	0.000	1.516	1.432	0.265	4.442
Energy waste for breath, cal/l	0.344	0.000	0.400	0.370	0.068	1.181
2002						
Number for the season, ind./l	2.009	3.479	1.639	10.657	3.717	
Daily diet, cal/l	0.037	0.324	0.332	5.039	2.865	8.597
Energy waste for breath, cal/l	0.010	0.087	0.087	1.302	0.732	2.219
2003						
Number for the season, ind./l	1.604	3.871	1.613	1.182	2.075	
Daily diet, cal/l	0.029	0.361	0.326	0.559	1.599	2.875
Energy waste for breath, cal/l	0.008	0.097	0.086	0.144	0.408	0.744

Appendix 54 (continued)

1	2	3	4	5	6	7
			Nevidim			
			2001			
Number for the season, ind./l	141.889	0.000	2.624	7.343	5.881	
Daily diet, cal/l	2.610	0.000	0.531	3.472	4.533	11.147
Energy waste for breath, cal/l	0.729	0.000	0.140	0.897	1.158	2.924
			2002			
Number for the season, ind./l	3.404	14.930	0.841	0.369	0.193	
Daily diet, cal/l	0.063	1.392	0.170	0.174	0.149	1.948
Energy waste for breath, cal/l	0.017	0.374	0.045	0.045	0.038	0.520
			2003			
Number for the season, ind./l	1.011	1.569	1.869	1.714	1.699	
Daily diet, cal/l	0.019	0.146	0.378	0.811	1.309	2.663
Energy waste for breath, cal/l	0.005	0.039	0.100	0.209	0.334	0.688

Appendix 55. **Change of percent of nauplii hatching at activation of cysts by 3 % peroxide of hydrogen within 20 minutes, %**

Cysts source	Control *A*	Experiment *B*	*B–A*	*B/A*	Cysts source	Control *A*	Experiment *B*	*B–A*	*B/A*
1	2	3	4	5	1	2	3	4	5
Kuchukskoye	36.8	45.6	8.8	1.2	Ebeyty				
Ulzhay					1	1.5	20.2	18.7	13.5
1	25.3	56.6	31.3	2.2	2	44.8	75.6	30.8	1.7
2	20.5	29.8	9.3	1.5	3	32	69.8	37.8	2.2
3	5.6	41.9	36.3	7.5	4	43	78.3	35.3	1.8
B. Yarovoye					5	41.3	74.6	33.3	1.8
1**	59.8	84.4	24.6	1.4	6	49.2	72.3	23.1	1.5
2**	61.8	68.5	6.7	1.1	7	27	65	38	2.4
3**	52.5	68.5	16	1.3	8	20.8	68.1	47.3	3.3
4	39	68.7	29.7	1.8	9	34.1	64.2	30.1	1.9
B. Kureynoye					10	39.4	71	31.6	1.8
1	55.6	70.2	14.6	1.3	11	20.5	66.5	46	3.2
2	66.4	75.2	8.8	1.1	12	21.3	73.2	51.9	3.4
3	29	68.9	39.9	2.4	13	30	54.3	24.3	1.8
Vishnyakovskoye					14	24.6	70	45.4	2.8
1	60.1	69	8.9	1.1	15	36.6	79.8	43.2	2.2
2	21.9	65.3	43.4	3.0	16	4.5	31.2	26.7	6.9
3	16.7	30.9	14.2	1.9	Gashkovo	35.8	85	49.2	2.4
4	17.6	56.3	38.7	3.2	Trebushinoye				
Nevidim					1	28.5	70.4	41.9	2.5
1	31.2	54.4	23.2	1.7	2	30.9	77.7	46.8	2.5
2	22.3	48	25.7	2.2	3	30.9	73.6	42.7	2.4
3	54.8	56	1.2	1.0	4	66.8	80.9	14.1	1.2
4	27.8	63.4	35.6	2.3	Aktoban				
5	67.7	78.4	10.7	1.2	1	32.8	55.8	23	1.7
6	67.7	78.2	10.5	1.2	2	77.6	79.7	2.1	1.0
7	80.7	89.5	8.8	1.1	3	63.4	87.9	24.5	1.4
8	57.7	72.2	14.5	1.3	4	81	81.4	0.4	1.0
9	74.3	83.4	9.1	1.1	Umreshevo	5.3	72.5	67.2	13.7

Appendix 55 (continued)

1	2	3	4	5
N.-Georgievskoye				
1	17.1	64.5	47.4	3.8
2	57.1	90.2	33.1	1.6
3	65	91	26	1.4
B. Medvezhye				
1	22.4	69.3	46.9	3.1
2	27.2	57.6	30.4	2.1
3	40.2	54	13.8	1.3
4	27.2	51.6	24.4	1.9
5	32.1	61.5	29.4	1.9
6	46	55	9	1.2
7	37	41.5	4.5	1.1
8	40	55.5	15.5	1.4
9*	50.7	54.1	3.4	1.1
Voskresenskoye				
1	29.3	79.5	50.2	2.7
2	49.9	73.2	23.3	1.5
Filatovo				
1	70.8	78.2	7.4	1.1
2	17.5	69.5	52	4.0
Filatovo				
3	52.1	73.1	21	1.4
4	46.9	58.9	12	1.3
5	58.1	65.6	7.5	1.1
6	41.5	62.7	21.2	1.5
7	59.4	85.7	26.3	1.4
8	52.9	63.4	10.5	1.2
9	70.1	76	5.9	1.1
10	28.3	68.2	39.9	2.4
11***	62.6	47.4	–15.2	0.8
12***	66.5	62.8	–3.7	0.9
13***	46	43.1	–2.9	0.9
min			0.4	1.0
max			67.2	13.7
M			25.8	2.3
σ			15.5	2.2
C_v, %			60.1	96.4
m			1.8	0.3

Note. * Cysts activated by cold; ** dry cysts; *** data did not consider at calculation of average values.

Appendix 56. **Change of percent of nauplii hatching at activation of cysts by 3 % peroxide of hydrogen within 20 minutes in depending on gradation of control parameters of hatching, %**

Number	Control *A*	Experiment *B*	*B–A*	*M*	σ	C_v, %	The difference is significant	*B/A*	*M*	σ	C_v, %
1	2	3	4	5	6	7	8	9	10	11	12
I	1.5	20.2	18.7	37.2	21.2	57.1	VI–VIII	13.5	10.4	3.7	35.4
	4.5	31.2	26.7					6.9			
	5.3	72.5	67.2					13.7			
	5.6	41.9	36.3					7.5			
II	16.7	30.9	14.2	38.1	16.8	44.2	V–VIII	1.9	3.2	1.0	29.9
	17.1	64.5	47.4					3.8			
	17.5	69.5	52				V–VIII	4.0			
	17.6	56.3	38.7					3.2			
III	20.5	29.8	9.3	38.1	11.0	29.0	V–IX	1.5	2.6	0.5	21.0
	20.5	66.5	46					3.2			
	20.8	68.1	47.3					3.3			
	21.3	73.2	51.9					3.4			
	21.9	65.3	43.4					3.0			
	22.3	48	25.7					2.2			
	22.4	69.3	46.9					3.1			
	24.6	70	45.4					2.8			
	25.3	56.6	31.3					2.2			
	27	65	38					2.4			
	27.2	57.6	30.4					2.1			
	27.2	51.6	24.4					1.9			
	27.8	63.4	35.6					2.3			
	28.3	68.2	39.9					2.4			

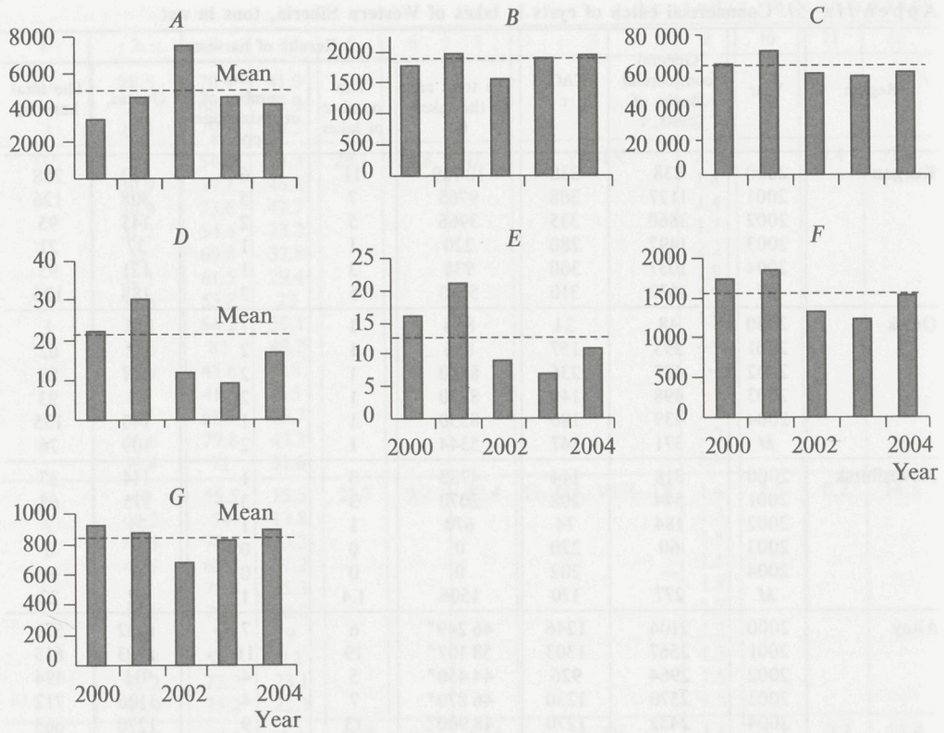
Appendix 56 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
III	28.5	70.4	41.9					2.5			
	29	68.9	39.9					2.4			
	29.3	79.5	50.2					2.7			
IV	30	54.3	24.3	29.1	13.8	47.3	VI–IX	2.5	1.9	0.4	21.2
	30.9	77.7	46.8					1.8			
	30.9	73.6	42.7					2.4			
	31.2	54.4	23.2					1.7			
	32	69.8	37.8					2.2			
	32.1	61.5	29.4					1.9			
	32.8	55.8	23					1.7			
	34.1	64.2	30.1					1.9			
	35.8	85	49.2					2.4			
	36.8	45.6	8.8					1.2			
	37	41.5	4.5					1.1			
	39	68.7	29.7					1.8			
	36.6	79.8	43.2					2.2			
	39.4	71	31.6					1.8			
V	40	55.5	15.5	21.7	9.2	42.4	II–III, VIII–IX	1.4	1.5	0.2	14.5
	40.2	54	13.8					1.3			
	41.3	74.6	33.3					1.8			
	41.5	62.7	21.2					1.5			
	43	78.3	35.3					1.8			
	44.8	75.6	30.8					1.7			
	46	55	9					1.2			
	46.9	58.9	12					1.3			
	49.2	72.3	23.1					1.5			
	49.9	73.2	23.3					1.5			
VI	50.7	54.1	3.4	15.7	9.9	63.1	I–IV	1.1	1.3	0.2	13.4
	52.1	73.1	21					1.4			
	52.5	68.5	16					1.3			
	52.9	63.4	10.5					1.2			
	54.8	56	1.2					1.0			
	55.6	70.2	14.6					1.3			
	57.1	90.2	33.1					1.6			
	57.7	72.2	14.5					1.3			
	58.1	65.6	7.5					1.1			
	59.4	85.7	26.3					1.4			
	59.8	84.4	24.6					1.4			
VII	60.1	69	8.9	13.8	7.4	53.7	I–IV	1.1	1.2	0.1	9.5
	61.8	68.5	6.7					1.1			
	63.4	87.9	24.5					1.4			
	65	91	26					1.4			
	66.4	75.2	8.8					1.1			
	66.8	80.9	14.1					1.2			
	67.7	78.4	10.7					1.2			
	67.7	78.2	10.5					1.2			
VIII	70.1	76	5.9	6.1	3.0	48.7	I–V	1.1	1.1	0.0	3.8
	70.8	78.2	7.4					1.1			
	74.3	83.4	9.1					1.1			
	77.6	79.7	2.1					1.0			
IX	80.7	89.5	8.8	4.6	5.9	129.1	III–V	1.1	1.1	0.1	7.0
	81	81.4	0.4					1.0			

Appendix 57. **Commercial catch of cysts in lakes of Western Siberia, tons in wet**

Region	Year	General commercial stocks of cysts, t	TAC, t	Results of harvests				
				The total area of the lakes, ha	The number of lakes	The number of organizations-suppliers	Quotas, t	The total harvest, t
Kurgan	2000	838	330	10 759	11	6	330	288
	2001	1127	308	9765	7	5	308	126
	2002	3860	335	3966	5	2	145	95
	2003	1497	280	220	1	1	37	21
	2004	1037	300	938	3	1	121	95
	M	1672	310	5130	5	3	188	125
Omsk	2000	48	24	864	1	1	24	1
	2001	393	157	864	1	2	62	62
	2002	477	236	8330	1	2	227	88
	2003	498	140	8330	1	2	93	93
	2004	439	180	8330	1	1	140	135
	M	371	147	5344	1	2	109	76
Novosibirsk	2000	318	144	4788	3	1	114	37
	2001	544	208	2070	3	3	175	64
	2002	184	74	670	1	1	21	7
	2003	60	220	0	0	0	0	0
	2004	—	202	0	0	0	0	0
	M	277	170	1506	1.4	1	62	22
Altay	2000	2104	1246	46 249*	6	7	1252	579
	2001	2567	1303	58 107*	19	11	1303	613
	2002	2964	926	44 450*	5	4	915	494
	2003	2570	1230	46 870*	7	4	1106	712
	2004	2432	1270	48 900*	13	9	1270	663
	M	2527	1195	48 915	10	7	1169	612
Khakasia	2000	21	10	265	1	1	10	10
	2004	10	0	0	0	0	0	0
Tuva	2000	8.5	0	0	0	0	0	0
	2004	8.4	0	0	0	0	0	0
Total...	2000	3338	1754	62 925	22	16	1730	915
	2001	4631	1976	70 806	30	21	1848	865
	2002	7485	1571	57 416	12	9	1308	684
	2003	4625	1870	52 420	9	7	1236	826
	2004	4203	1952	58 168	17	11	1531	893
	M	4856	1825	60 947	18	13	1530	837
	C_v	32	9	10	46	44	17	11

Note. * The shallow part of Kulundinskoe Lake is not considered.



App. 58. Commercial catch of cysts in lakes of Western Siberia for the five years' period. *A* — total stocks of cysts, t; *B* — the TAC (total allowable catch), t; *C* — total area of lakes which was made harvest, ha; *D* — number of commercial lakes, pcs.; *E* — number of organizations-users of harvest; *F* — allocated quotas, t; *G* — volume of harvested cysts, t.

Appendix 59. **Commercial lakes and volumes of annual harvests of cysts within 1999–2003, t**

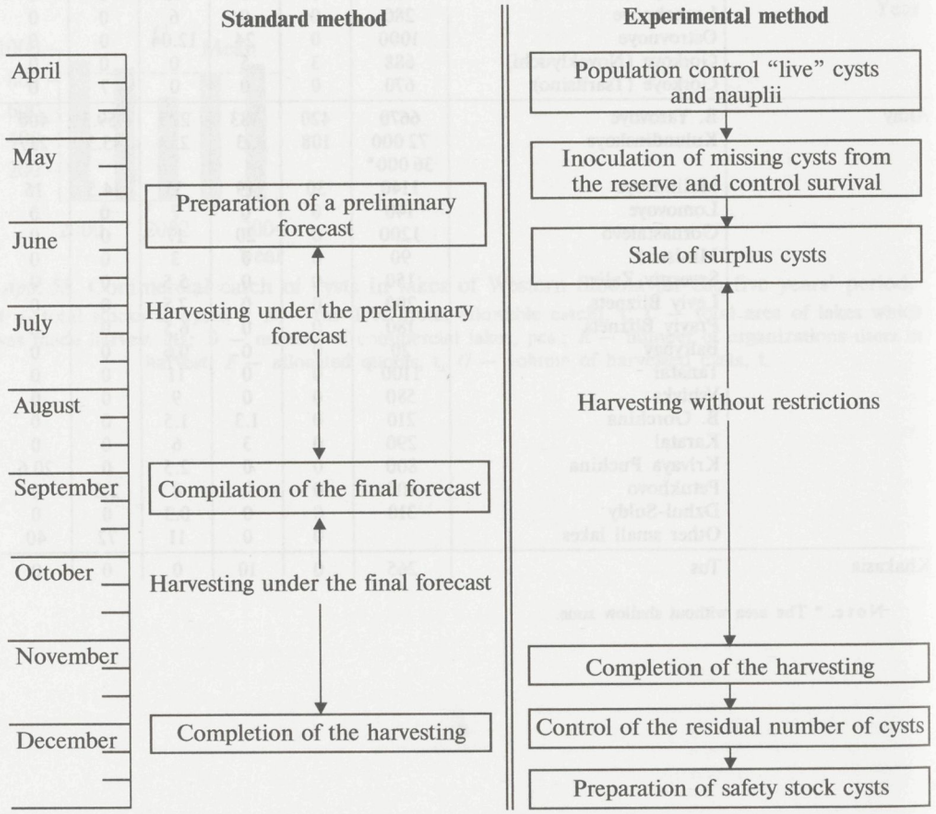
Region	Lake	Area, ha	Years of harvest				
			1999	2000	2001	2002	2003
Kurgan	N.-Georgievskoye	203	0	36.9	0	1.3	0
	Nevidim	718	0	21.2	18	43.7	0
	Vishnyakovskoye	220	0	39.9	8.3	0	21
	Trebushinoye	308	0	5.9	0	44.4	0
	Filatovo	2367	0	20.7	26.3	5.1	0
	B. Kureynoye	370	11.3	0.5	0	0	0
	B. Medvezhye	3830	0	92	35.3	0	0
	M. Medvezhye	1810	38	61	35	0	0
	Aktoban	661	0	5.3	3.2	0	0
	Cherdynskoye	159	0	2	0.2	0	0
	Voskresenskoye	113	0	2.4	0	0	0
Omsk	Ebeyty	8330	0	0	0	87.5	93
	Ulzhay	864	0	0.9	62	0	0
Novosibirsk	Chebakly	3100	0	8	0	0	0
	Gorkoye (Barabashi)	790	0	0	46	0	0
	Lechebnoye	280	0	0	6	0	0
	Ostrovnoye	1000	0	24	12.04	0	0
	Gorkoye (Novoklyuchi)	688	3	5	0	0	0
	Gorkoye (Tsaritsino)	670	0	0	0	7	0
Altay	B. Yarovoye	6670	420	483	225	359.3	400
	Kulundinskoye	72 000 36 000*	108	53	257	45.3	237
	Malinovoye	1140	30	19	35	14.5	15
	Lomovoye	140	0	0	7	0	0
	Gornastalevo	1200	0	20	17	0	0
	Ministral	90	0	0	3	0	0
	Severniy Zaliv	150	0	0	5.5	0	0
	Leviy Bliznets	200	0	0	7.5	0	0
	Praviy Bliznets	180	0	0	6.5	0	0
	Baltybay	20	0	0	0.6	0	0
	Tanatar	1100	0	0	11	0	0
	Vshivka	580	0	0	9	0	0
	B. Gorchina	210	0	1.3	1.5	0	0
	Karatal	290	0	3	6	0	0
	Krivaya Puchina	800	0	0	2.5	0	20.6
	Petukhovo	400	0	0	8	2.5	0
	Dzhul-Suldy	310	0	0	0.3	0	0
	Other small lakes		0	0	11	72	40
Khakasia	Tus	265	0	10	0	0	0

Note. * The area without shallow zone.

Appendix 60. **Harvest of cysts in lakes of Western Siberia for the period within 1995–1999 and comparison with harvest within 2000–2004**

Parameter	1995	1996	1997	1998	1999	*M*	Compared with 2000–2004
The total biomass of cysts in the lakes with harvested cysts, t	4311	3879	1498	2566	3439	3139	<1700 (50 %)
TAC of cysts, t	1890	1594	566	1070	1913	1407	<420 (30 %)
Harvest cysts, t	420	414	85	1118	640	535	<300 (60 %)
Biomass of harvested cysts, kg/ha	26.6	13.7	8.8	25.1	10.9	17.0	>4 (30 %)
Productivity of lakes, kg/ha	272.68	128.75	155.88	57.627	58.706	135	>55 (70 %)
The total area of the lakes, used in the fishery, ha	15 810	30 128	9610	44 528	58 580	31 731	<29 200 (90 %)

Note. Data for 1995–1999 years on Altay region are taken from the literature (Novoselova et al., 2000).



App. 61. Scheme of hydrobiological works on calculation Artemia cysts TAC (total allowable catch).

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