Hydrotechnical Construction, Vol. 32, No. 12, 1998

ASSESSMENT OF THE ECOLOGICAL SITUATION IN THE BASIN OF THE KISLOGUBSK TIDAL ELECTRIC POWER PLANT

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The ecosystems of the Gulf of Kislaya and the basin for the Kislogubsk tidal electric plant and the water body of the Gulf of Ura, which is adjacent to the basin, have been investigated under the aegis of the S. Ya. Zhuk All-Russian Scientific-Research Institute for Design and Exploration with the participation of specialized organizations since 1924. Results of this detailed ecological monitoring are reflected at great length in monographs [1, 3]. The assessment presented in this paper for the ecological situation in the basin of the Kislogubsk TEP was made from results of field studies conducted by students under our guidance in the summer months from 1994 through 1996.

Working in the large-scale relatively uniform water bodies, the researchers were required to collect a large volume of factual material to ascertain existing statistical laws. The cost of this type of experimental studies, which is equally as costly as subsequent pictorial processing of the material collected, is excessively high. The idea of a search for quantitative interrelations based on an appreciably smaller amount of material that can be obtained in small isolated water bodies, where the values of the abiotic parameters vary over a restricted area, is alluring in this connection. Semi-closed marine water bodies – fiords, bays, atoll lagoons, the caldera of extinct volcanoes, etc. – correspond to these requirements. Although these water bodies may be distinguished by certain specific traits, they can on the whole, be analyzed as natural models of ecosystems in coastal waters. Research in similar model water bodies with expressed gradients in the medium makes it possible to obtain a response from hydrobionts with the maximum possible number of different combinations of medium parameters. This is a means of the forecast modeling of relations between biotic and abiotic components of coastal marine ecosystems [4].

The basin of the Kislogubsk TEP, which is subjected to a broad spectrum of anthropogenic activity, is a convenient entity for this kind of research. It is interesting to assess the response of the biota in the Gulf of Kislaya to different ecological factors. In perspective, the Gulf of Kislaya may become a testing ground for the development of principles for management of the entire northern coastal zone.

We conducted research in the Gulf of Kislaya and its adjacent gulf during the summers of 1994-1996 within the framework of the UNESCO-sponsored program "Baltic Floating University" (a division of "Sever") [8] to develop principles for the monitoring of marine coastal natural-technical systems and to assess the modern state of ecosystems of the gulf. To achieve this goal, a set of hydrochemical, hydrooptical, hydrobiological, and accompanying meteorological observations were conducted in the water bodies of the Gulfs of Kislaya and Ura. The unregulated Gulf of Ura was selected as a control (standard) entity for comparison of observational results. The experimental studies were performed with small boats by the round-the-clock lookout method. We made more than 400 bathometric series of determinations of the temperature and salinity of the sea water, and its content of oxygen, phosphates, and nitrates, and more than 500 soundings with an SDT-sonde; 36 hydrobiological diving stations for benthos sampling and underwater photography, and 20 hydrobiological stations for sampling of plankton and benthos were also established. Water samples were chemically analyzed in a field laboratory equipped by expeditionary forces of the Polar Scientific-Research Institute of Fisheries and Oceanography. Primary processing of data on temperature, salinity, dissolved oxygen, and biogenic elements, and the construction of three-dimensional fields and vertical sections of the distribution of characteristics were carried out on site with the use of a personal computer. The magnitudes of the tidal fluctuations were measured from data of a sea-level recorder installed at the TEP.

The coastline was mapped with the separation of characteristic biotopes. Microdistricting of the water bodies investigated on the basis of the space-time variability of the characteristics measured was performed, the response functions of the biota constructed, and the extent of the influence exerted by individual biotic and abiotic factors of the medium on the quantitative characteristics of the distribution of the most representative species ascertained after the observational data had been processed. The quantitative relationship between benthos characteristics and

Translated from Gidrotekhnicheskoe Stroitel'stvo, No. 12, pp. 25-30, December, 1998.

0018-8220/98/3212-0727$20.00

priority factors of the medium were investigated, using multiple regression analysis. Station-by-station populations and biomasses of the most representative species, the weighted average-daily duration of drying, and the salinity were used in formulating the regression equations. The self-organizing models of the distribution of representative species were designed in accordance with the combiner algorithm of the MGAA (method of grouped argument accounting) [4]. Response surfaces of the benthos characteristics (populations and biomasses) were constructed on the variation of basic factors of the medium (tidal amplitudes, weighted average-daily duration of drying, and salinity) using the applied software package "Surfer." The extent of the influence exerted by these factors and their priorities were determined from the pattern of the response surfaces.

It is necessary to point out that the benthos was selected as the subject of monitoring in connection with its conservativeness and long- term attachment to certain biotopes.

The surface distribution of temperature and salinity in the Gulf of Kislaya was represented by fields with average temperature values of 10.2°C and salinities of 30.8%. The exception was the section adjacent to the dam, where a strong adjective current, which carries a saltier (by 2%) and warmer (by 0.5°C) water is clearly traced in the distribution of thermal characteristics. It is presented that interyear fluctuations of average surface temperature may exceed 5°C. Conversely, the surface temperature in the Gulf of Ura, which is deeper and more openly connected to the Barents Sea, varies very negligibly. The hydrooptical characteristics vary synchronously with temperature. The vanishing depth of the white disk has fluctuated from 7 to 15 m. Indicators of solar-radiation weakening have varied accordingly. Obviously, this is associated with less vigorous development of phytoplankton, which exert a basic influence on the turbidity of the water of the basin under consideration in cold years.

Analysis of the results obtained suggest the existence in the basin of the Gulf of Kislaya of two near-surface water masses (northeastern and southwestern), which are separated by a well expressed frontal division that appears in all measured hydrological, hydrotechnical, and hydrochemical characteristics. The southwestern water mass is formed under the action of fresh-water runoff of large water courses. The northeastern water mass forms primarily due to water exchange through the tidal electric powerhouse. According to measured characteristics, this mass can be referred to waters of the adjacent Gulf of Ura. The boundaries of the water masses are traced more distinctly on the vertical sections. In that case, a third mass is clearly isolated – a near-bottom slowly-moving water mass, which is uniform with respect to density and which has filled the deep-water sections of the basin (Fig. 1). The basic picnocline separates the near-bottom water mass from both near-surface masses, being located in a 12-20-m layer in the northeastern part of the gulf, and in a 5-20-m layer in the southwestern part. The plankton communities of the northeastern and near-bottom water masses are marine in terms of composition, and are somewhat depleted as compared with those in the Gulf of Ura. In the southwestern water mass, the population of marine organisms is still more depleted, whereas fresh-water forms that gain access to the gulf through the water course from Presnogo Lake are encountered.

The pH value in the water body of the gulf is placed in the range from 8.2-6.4, with the exception of regions near the mouths of water courses, where it drops to 6.0.

The average content of dissolved oxygen in the surface layer varies from 6.7 to 6.9 g/liter; this is 102-105% of saturation. The layer of maximum oxygen saturation (120 to 146%) is located at a depth of 5-10 m. Beginning from a depth of 20 m, the oxygen content in the water decreases, and does not exceed 1 mg/liter (13% of saturation) in the near-bottom layers of both trenches. An acute oxygen deficit is observed at the bottom of the southern trench. Soil samples taken here from a depth of 36 m are represented by a mud with a characteristic black color and an odor of hydrogen sulfide, and contains no living organisms or their remains. This trench has most likely never been inhabited by hydrobionts. Numerous valves, crayfish, and mollusks, and single living specimens are observed in the bottom of northern trench. Obviously, the colonization of this trench is continuing at the present time.

The pattern of the vertical distribution of biogenic elements, and, among other things, nitrites, suggests a nearly complete lack of exchange between the surface and deep layers. The content of nitrites in the 0-10-m layer varies from 1 to 7 μg/liter over the entire water body. It increases to 26 μg/liter in the trenches, beginning at a depth of 20 m. The existence of a layer with minimum nitrite concentrations at a depth of 15 m is in good agreement with the location of the jump layer, which has been isolated by hydrological data.

The concentration of phosphates in the upper 20-meter layer does not exceed trace values. The maximum contents of phosphates (10-15 μg/liter) are observed in the trenches below 20 m.

Two types of benthos communities are isolated in the tidal zone (Fig. 2). A community in the stony littoral is formed primarily by 10 species. They are the sirripedia snake weed "marine acorn" Sembialanus balanoides; the gastropod mollusks (snails) Littorina littorea, Testudinalia tesselata, Margarites groenlandica, and Bussinum undatum; the two-shell mollusk Mytilus edulis; the sandhopper Gammarus setosus; the sea urchin Strongulocentrotus droebachiensis; and, the multispined worm Nereis virens and the hermit crayfish Pagurus pubescens. The "marine acorn" is the background-forming species. The density of its colonies among the stones varies from 40-60 to 100 specimens/m^2.

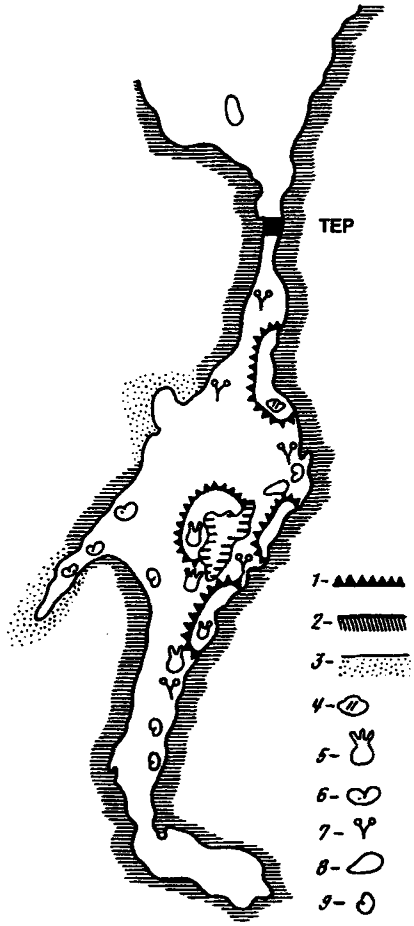

Fig. 1. Diagram showing Kislaya Gulf and TEP basin with data derived from 1994-1996 investigations: 1) region of diver studies; 2) community of stony coastline; 3) community of silty-sandy soils; 4) scallops' shoal; 5) colonies of sea anenomes; 6) colonies of mussels; 7) brown algae; 8) modiolus; 9) periwinkles.

A community formed by three leading species is observed on the silty-sandy shoals in the small lagoons of the western shore of the gulf: the Chironomus salinarius, the two shell mollusk Mya truncata, and the sandhopper G. Setosus. In terms of composition, the first community is marine, and the second a transitional community from brackish to marine. The composition of both communities is depleted as compared with analogies from the Gulf of Ura. Our attention is therefore turned to the lack of colonies of sand-dwelling worms Arenicola marina, which are common to Western Murman. On the stony littoral, Fucus vesiculosus was found to be the only species of brown algae that forms rather dense overgrowths. As in the neighboring bodies of water, however, this species does not form a continuous border. The plant-poisoning snail Littorina saxatilis is observed only in the southern part of the tip of the gulf, where its numbers reach 300 specimens/m^2. This is obviously caused by the admission here of biogene-rich river water (at the mouth of the river, the stones on the littoral are covered with an algoid incrustation, the scraping off of which also feeds the snails.

A thinned colonies of the two-shell mollusk Modiolus modiolus (in the middle of the gulf) and colonies of the sea anemone Metridium senile (in the upper and middle section) are observed in the sublittoral. The scallops' shoal was mapped at the boundary between the estuarian and middle sections of the gulf from results of diver investigations (Fig. 2). Reserves of the scallop Chlamys islandicus are negligible. Considering that the colonies of the edible mussel M. Edulis are not so dense as to have practical value, it is possible to state the absence of commercial accumulations of bentonite-bearing organisms in the water body under investigation.

Analysis of the abiotic conditions enable us to state that in "normal" years for benthos development, the freshening of the surface layer of water, the character of the soil affecting the formation of some type of communities, and the technogenically transformed high tide, and, in particular, such characteristics as peak level fluctuations and

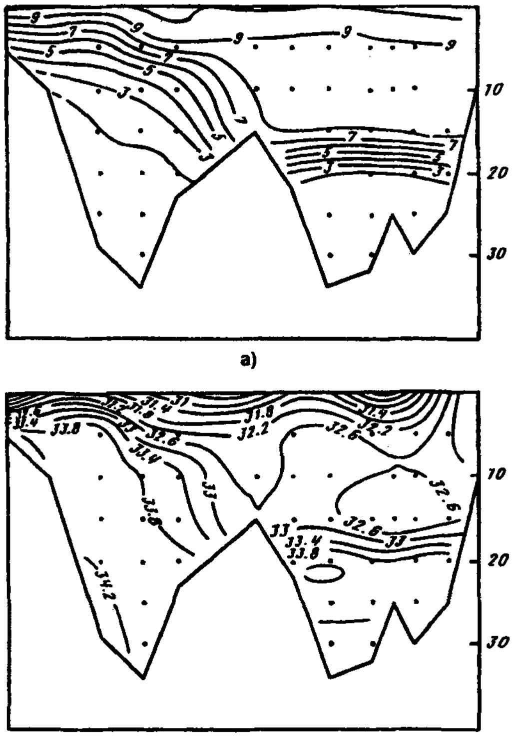

Fig. 2. Distribution of temperature, °C, (a) and salinity , %, (b) in section along Gulf of Kislaya during summer of 1995. Tip of gulf and dam of TEP are laid off to the left and right, respectively, on the axis of abscissas. Depth in meters is laid off against the axis of ordinates.

duration of drying are limiting factors in the tidal strip. The development of benthos at the bottom of the trenches is limited by an oxygen deficit.

A register of the most representative types of benthos species, which can be used as specie monitors for long-term monitoring in the Gulf of Kislaya, has been compiled from results of the observations. These species are the L. Littorea, M. Edulis, M. Truncate, and S. Droebachiensis. Its use is most expedient for monitoring of the specie pair littorine L. Littorea + mussel M. Edulis. These mollusks are massive, have a broad range, are readily distinguishable at depth, and comparatively minor traits are required for their identification. For measurement, they can be easily flushed from their habitat without detriment and can be returned to the natural colonies.

In addition, the ecology of the species in question differs significantly. The littorine snails actively optimize their own position in space, and react to the approach of a storm and to the most minute changes in the ecological setting. The significant response of the snails to pollution of the medium is ascertained. In 1995, therefore littorines migrated from the estuarian portion of the gulf, where an emergency discharge of diesel fuel occurred a short time before. The enumerated behavioral traits make it possible to analyze the littorine as a "mobile species," which is sensitive to fluctuations in abiotic factors.

The two-shell mollusks M. Edulis are characterized by a sessile existence and a higher sensitivity to changes in environmental parameters as compared with the snails (due to the isolating closure reflex of the valves). Thus, the species under consideration form a pair of stationary resistant/mobile sensitive representatives of different ecological strategies. The information on the pair of species in question can be expanded to the entire littoral benthos with a sufficiently high probability.

The surfaces of the response of littorine abundance to changes in environmental factors indicate that their population N and biomass B (Fig. 3) vary approximately similarly in response to changes in salinity and duration of drying. The abundance of snails decreases with increasing duration of drying. The dependence on a change in salinity is more complex in nature. The minimum value of the abundance indicators is recorded for salinities ranging from 30.3 to 30.7%. The population and biomass begin to increase as the salinity deviates on the lower or higher side.

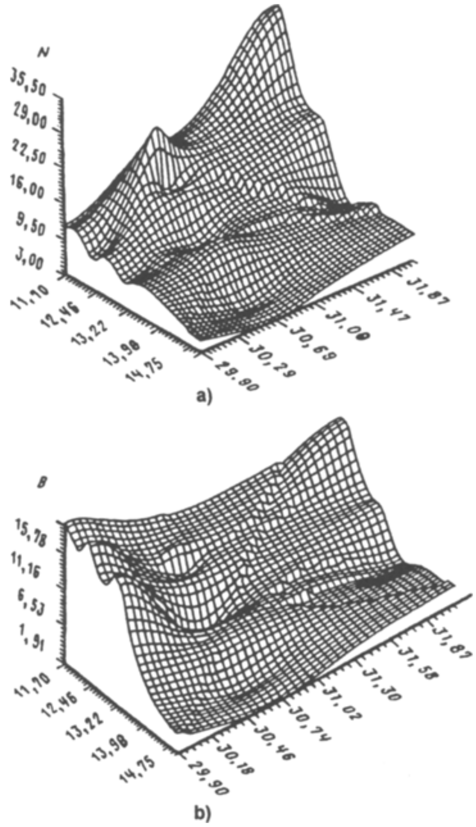

Fig. 3. Surfaces of response of abundance indicators of gastropod-littorine colonies to changes in abiotic environmental conditions from 1994-1996 studies. Population N in specimens/m (a) and biomass B of gastropods in g/m^2 are laid off against the axis of ordinates. Duration of drying period in h and average-daily salinity in % are laid off to left and right, respectively, against axis of abscissas.

Response surfaces constructed for the M. Edulis have an even more complex shape. They were found to be far from the classical bell-shape distribution curves of biological variables with respect to environmental gradients [6]. The curves constructed apparently represent only a fragment of the normal bell-shape curves. It is also not excluded that significant deviations from a bell-shape distribution are caused by the vigorous influence of factors that have not been more precisely defined (the extent to which the surf breaks, the oxygen regime, etc,).

The anomalies of hydrological year 1996, when a meter layer of essentially fresh water was observed everywhere on the surface of the TEP basin, were caused by the thawing of snow that had continued to the middle of July; the height of the snow had reached 3 m on the coastline during the previous winter. A clearly expressed vertical density stratification in a 0.6-1-m layer led to the appearance of a "turbid" layer of diffusion mixing, where numerous small-scale intrusions of sea water into the surface of the fresh water gave rise to repeated diffraction and scattering of light rays due to which the flux of natural illumination rapidly weakened with depth, and the transparency of the surface waters was low. High vertical stability in the near-surface layer essentially completely blocked turbulent fluxes of heat and salt. At the windless threshold during the period of level equilibrium, the flow velocity in the water body of the gulf did not exceed 3 cm/sec; this dictated the existence of a virtually laminar hydrodynamic regime and quasi-molecular heat and salt exchange in the one-meter surface layer. The lower boundaries of the halocline and thermocline were depressed to a depth of 15-25 m (by 2-3 m in the deep sections of the water body) along the shoreline slopes. This Downbelling effect is absent near the vertical walls; this enabled us to explain it by the boundary effects of the shallow water.

Heavy continental runoff has ensured a high concentration of silicon in the waters of the gulf – a biogenic element required for plankton diatoms. In the 5-meter surface layer, however, reserves of silicon were found to be unneeded. There was no plankton colony here due to rigorous freshening. As a minimum, the silicon concentration dropped- off by an order at a depth of 5-15 m; it was precisely here that plankton flourished. In the near-bottom layers with a low temperature and significantly lower salinity, which are unfavorable for the viability of plankton, the silicon concentration increased agin to values close to those on the surface.

A "seasonal phase shift" in the development of plankton, which in July, had retained the "spring" shift in terms of its composition, was noted in an anomalously cold year. The littoral benthos communities were in a depressed state due to rigorous freshening. The numbers of the representative species was reduced by an order. Mobile species (sea urchins, starfish, scallops, sea anemones, and sea cucumbers) moved from the fresh surface water to greater depths.

In the standard Gulf of Ura, the described effects were smoothed over due to vigorous exchange with the waters of Motovsk Bay. It is therefore possible to speak of a clearly expressed reaction of biota to the observed anomalies in the abiotic characteristics of the coastal waters.

The research that we conducted makes it possible to assess the current ecological situation in the Gulf of Kislaya as quasi-stable on the whole. On the one hand, the specie diversity of the benthos and plankton is being maintained at a rather high level. On the other hand, the formation of the ecosystem in the gulf is apparently still incomplete today. The ecosystem that is being formed differs from the initial one, corresponding to the new abiotic conditions. In anomalous years, the biota of the gulf are subject to the short-term shock effect of fresh melt water. Specie depletion and lower stability as compared with the control ecosystem of the Gulf of Ura, the dependence on the tidal electric plant, and preservation of salt-water species can be considered basic characteristic features of the natural-technical systems of the basin. The littoral (by reason of the possibility of vigorous freshening) and trench depressions (due to oxygen deficit) can be called zones of ecological risk.

It is possible to optimize the ecological situation in the basin of the Kislogubsk TEP, using the following system of recommended engineering-technical measures:

operation of the hydraulic-generating set of the TEP only in a continuous ecologically safer regime;

creation in the littoral zone of artificial biotopes in the form of synthetic algae, which do not react to freshening and which attract mobile forms of hydrobionts; and,

the delivery of cold aerated water to the oxygen-depleted trenches via pipeline from the Gulf of Ura.

The creation of a center for marine-culture development at the TEP base is of interest. A wealth of experience gained through cooperation between power engineers and pisciculturists has been accumulated in the Murmansk Oblast. Automated piscicultural plants, which are operated by the "Arctic Salmon' Company and which utilize heat releases to the air and reservoir, and, in turn, free the environment of heat pollution, are functioning in rooms of the Upper Tuloma hydroelectric plant. It is also expedient to use the experience gained through the cooperation of various nature managers in the Gulf of Kislaya. Hatcheries of an experimental fish farm run by the Polar Scientific-Research Institute of Sea Fisheries and Oceanography, where procedures are being developed for the breeding of rainbow trout, humpbacked salmon, and cod (including the use of planting stock and feed from the "Arctic Salmon" Company) are situated along both sides of the TEP dam. Studies are being conducted here on the adaptation of the Kamchatka crab, the breeding of sea anemones in fish hatcheries, and refinement of the procedure employed to collect their roe. Use of unqualified feeds or their overdosing may result in the fact that the excess polluting organic material will enter the depressions of the gulf; this will be even more harmful to their oxygen regime. Comprehensive consideration of the anthropogenic load on the Kislogubsk natural-technical system is obviously possible only on the basis of the interdisciplinary approach with the cooperation of specialists of their own different profiles. In our opinion, it is, in perspective, expedient to utilize the specialized program "Coastal zone," which the authors set about to create in conjunction with the Institute of High-Speed Calculations and Data Bases, to ensure the complex ecological monitoring of the Kislogubsk type of marine coastal natural-technical systems.

Conclusions

1. The bases of methods for rapid analysis of the ecological condition of marine coastal natural-technical systems with small floating facilities at a shallow depth, using minisondes and diving methods to observe biota were developed during the investigations. A procedure has been developed for processing information obtained under field conditions with the use of computer data bases. A procedure has also been worked out for qualitative assessment of the effect of natural and anthropogenic factors on the biota.

2. The current ecological situation in the basin of the Kislogubsk TEP is being evaluated as quasi-stable, requiring monitoring from specialists of different profiles – power engineers, ecologists, hydraulic engineers, oceanologists. The ecosystems of the Gulf of Kislaya are less stable as compared with the standard ecosystems in the adjacent Gulf of Ura due to a reduction in natural water exchange through the TEP. Their stability can be improved by observing the planned three-shift operating regime for the TEP, or by passing an adequate flow through the penstocks of the TEP. The implementation of a set of proposed engineering measures is also expedient.

3. The creation of a permanent observation post at the TEP is expedient for continuation of complex ecological monitoring in the basin of the TEP. In our opinion, use of labor-saving procedures for the acquisition, processing, and analysis of data, the systems approach, broad use of multidimensional methods of data analysis

and computer techniques, and representation of final results in a form convenient for the development of formalized solutions should be regarded as principles basic to the implementation of monitoring.

4. It is suggested that the experience gained with the rapid-assessment of the ecological situation in the basin of the Kislogubsk TEP in 1994-1996 be used for the ecological inspection of projects involving future tidal plants. The results obtained can be used as the basis for development of principles for the monitoring of marine natural-technical systems in the coastal zone and on the shelf of the Barents Sea.

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