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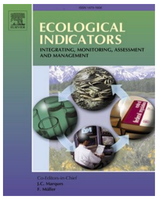

Original Articles

Methodological approaches to phytomediation of productive processes in chalk quarry reservoirs of Belarus

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ABSTRACT

As concerns field work, bathymetric measurements as well as measurements of physical and chemical parameters of water were conducted, and samples were collected for laboratory tests, which included quantitative and qualitative hydrobiological analyses concerning e.g. the abundance, biomass and species composition of phytoplankton, seston and chlorophyll. Six water bodies (situated in flooded chalk pits) with different morphometric parameters (areas ranging from 2.22 to 37.67 ha, depths ranging from 5.1 to 23.0 m and near-shore shallow areas ranging from 0.39 to 2.64 ha) and with different bioproductive characteristics of water mass (eg. transparency – 1.2–6.8 m, phosphates – 0.002–0.110 mg/dm^3, nitrates – 0.040–0.600 mg NO^{-}_{3}/dm^3, biomass of phytoplankton – 0.075–1.801 mg/dm^3, seston – 0.73–5.56 mg/dm^3) were selected for the study of the phytomediation mechanism. The specificity of structural and functional relationships between the abiotic and biotic components of productive-macrophyte and productive-phytoplankton reservoirs is determined. It was established that macrophyte water bodies in flooded chalk pits are able to maintain their basic production and trophic characteristics in the long term under anthropogenic influence conditions. An algorithm is proposed for calculating the level (E – 89.58–115.13), productivity index (K – 11.16–54.15) and gradient (E – 2.1–9.8) of eutrophication of chalk (limestone) quarry reservoirs using the morphometric specificity indicator of the trophogenic epilimnial layer ($S\tau$ – 0.05–0.270). The revealed dependence of the productive and functional organization and trophic status of a quarry reservoir on the morphometric features of a technogenic basin is proposed to be used in the design of sustainably functioning macrophyte-type aquatic systems at the stage of mining and engineering reclamation. The possibility of creating ecologically sustainable lake-type aquatic systems on the site of resource depleted chalk quarries in the process of phytomediation of productive processes is substantiated. Research on innovative methods of reclamation of flooded chalk pits is in line with several sustainable development goals.

1. Introduction

The relevance of assessing the current state and prospects of development of newly formed reservoirs (ponds) is determined by the progressive increase in the open-pit mining of non-metallic minerals and a significant growth of water reclamation fund – one of the most promising areas of restoring the economic value of disturbed lands (Castro and Moore, 2000; David, 2007; Castendyk and Eary, 2009; Dal Sasso et al., 2012; Khomitch et al., 2015; Kubiak, et al., 2018). Water-flooded chalk (limestone) quarries have a fundamental similarity with natural limnic systems in their hydro-chemical, bio-productive, and sedimentation processes (Axler et al., 1998; Khomitch, 2002b; Khomitch et al., 2012; 2013; Makarevich and Savich, 2014; Blanchette and Lund, 2016; Luek and Rasmussen, 2017; Jawecki et al., 2019; Kilonzo et al., 2019), and they also characteristically exhibit a number of specific features due to the technogenic (man-caused) nature and youth of the basin. Unlike natural lakes, in quarry reservoirs, the stabilization of productive and functional structure and the formation of mechanisms of resistance to

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various natural and anthropogenic eutrophying effects are just taking place. This feature of the newly formed aquatic systems becomes even more intense due to their small size and weak inertial properties of small volumes of water masses.

The tourist and recreational use of chalk quarry reservoirs (ponds) associated with the active influence of eutrophying factors requires an assessment of the current productive and trophic status, the rate of eutrophication processes, registration and use of natural mechanisms of sustainability of water reclamation sites. In this respect, the sustainability of newly formed quarry reservoirs is understood as the ability of a system experiencing external influences to maintain its productive and functional structure and perform its natural and economic functions within specified limits (Alekin et al., 1973; Eary, 1999; Akasaka et al., 2010; Schultze et al., 2010; Bajchorov et al., 2014; Romanov, 1989; Rumiantsev, 1977).

The mechanism that compensates for the impact of anthropogenic influences is embedded in the structure of interactions between the biotic and abiotic elements of the system. In the process of evolution of a reservoir, the presence of a biotic component determines its ability to actively preserve its basic productive and trophic characteristics. It is the presence of the biotic component in the system that ensures the compliance of a limnic system with changing external conditions as well as preservation of the productive-functional structure: of macrophyte type in macrophyte reservoirs, and of phytoplankton type in reservoirs with phytoplankton development (Pokrovskaya et al., 1983; Galas, 2003; Krolová et al., 2013; Lukács et al., 2015). During their natural evolution, macrophyte reservoirs prove to be more viable and sustainable than phytoplankton ones. However, in contrast to phytoplankton lakes, reservoirs with macrophyte orientation remain highly transparent, not contaminated by massive accumulations of planktonic algae. It is the ability of macrophyte lakes to maintain a consistently low level of the productive activity of phytoplankton, which guarantees high water quality, even when it reaches a high trophic status, makes them the optimal prototype for the design of reservoirs for tourist and recreational use at the site of depleted chalk quarries-depressions. The aforementioned phytomediation potential of the eutrophication process in macrophyte reservoirs is based on the specific functioning of submerged macrophytes, which extract nutrients not only from water but also from bottom sediments, and for this purpose use both the leaves and the root system (Khomitch et al., 2012; Khomitch et al., 2015; Calado et al., 2019; Yu et al., 2019; Xu et al., 2021). The tissues of submerged macrophytes have the ability to intercept nutrients both from the bottom layer of water in contact with the soil and from the surface runoff water entering from the catchment area (Yu et al., 2019).

Taking into consideration the aforementioned advantages of the functioning of macrophyte-aquatic systems in addressing the issue of creating environmentally sustainable quarry reservoirs for tourist and recreational purposes, the main goal should be their development in a macrophyte way. Among the intra-limnic preconditions for the formation of a macrophyte type of functioning, the key role belongs to the morphometric parameters of the basins, which determine the features of the thermal stratification of water mass. The formation of open-pit (quarry) basins with specified morphometric parameters can be carried out at the stage of mining and technical reclamation of depleted chalk pits using the existing dependence “morphometric parameters of the basin – indicators of the trophic status of the aquatic system”.

The objectives of this study included:

- study of morphometric parameters of model newly formed flooded chalk pits;
- analysis of the dependence of the productive-functional organization of a quarry reservoir and its trophic status on the morphometric features of a technogenic basin;
- development of an algorithm for calculating the level, productivity index and gradient of eutrophication of chalk quarry reservoirs using the indicator of morphometric specificity (identity) of the trophogenic epilimnial layer of technogenic open-pit (quarry) basins;
- selection of tools for express assessment of the trophic status of existing reservoirs and procedures for predicting the response of newly formed aquatic systems to their economic use for tourist and recreational purposes;
- development of recommendations for the formation of optimal morphometric parameters of basins that allow higher aquatic vegetation to colonize (acclimate in) the reservoir, to provide the macrophyte type of organic matter production, the participation of submerged macrophytes in the phytomediation processes of chalk quarry reservoirs (ponds) in Belarus.

2. Materials and methods

2.1. Geographical location and morphometric parameters of the basins

A group of flooded chalk quarries (Ross deposit) near the urban-type settlement Krasnoselskiy: Goluboy (Blue), Lazurnyi (Azure); Linza-14 (Lens-14) (Kolyadichi deposit); as well as the Krichev quarry reservoir and the Khotinovo-1 and Khotinovo-2 quarry reservoirs, were chosen as model targets for studying the possibility of tourist and recreational use of water reclamation sites (Figs. 1-3, Table 1).

2.2. Fieldwork and laboratory-based work

Previously collected data on the morphometric parameters of the basins, hydro-chemical and hydro-biological parameters of the studied reservoirs was updated at the end of the summer season 2018 (Khomitch et al., 1983; Khomitch, 2002b; StatSoft, 2009). The content measurement of the components of salt composition and biogenic elements in the waters sampled from the surface and bottom horizons of the chalk (limestone) reservoirs Goluboy, Lazurnyi, Linza-14, Krichev, Khotinovo-1, Khotinovo-2, was carried out at the Branch “Central Laboratory” of the Republican Unitary Enterprise “Research and Production Centre for Geology” (Republic of Belarus). The morphometric analysis of water reclamation sites was carried out following the results of plane-table (menzular) and bathymetric surveys. Bathymetric plans were drawn up on the basis of EagleFishID 128 echo sounder depth measurements, which were conducted within a square grid of approximately 20 m. Measurement points were located by GPS. Based on the depths assigned to measurement points, interpolation was performed with isobaths every 2 m. Bathymetric schemes were drawn up using the QGIS software. The calculation of morphometric parameters of the basins was performed using the formulas generally accepted in limnology (Yakushko, 1981; Imberger and Patterson, 1989). Transparency was measured using the Secchi disc (Rumiantsev, 1977). Water samples for determination of hydro-chemical parameters were taken in the deepest parts of reservoirs taking into account the thermodynamic condition of water masses, and in the coastal littoral area taking into account the acclimation of submerged macrophytes. Data on the vertical distribution of temperatures was obtained using a GR 41 M−1 electric thermometer. The concentrations of biogenic elements (plant nutrients) were determined through colorimetric estimation. Ammonium molybdate and tin (stannous) chloride were used to determine total and mineral phosphorus (Shilkrot, 1981; Jarvie et al., 2002). Total phosphorus was determined in unfiltered water samples, phosphorus-containing organic compounds were destroyed in the presence of sulphuric acid and persulphate during half an hour boiling of the sample (Blomqvist et al., 1993; Zhuhovickaya and Generalova, 1991). Concentrations of nitrite nitrogen and ammonia nitrogen were determined in the first case using α-naphthylamine and sulphanilic acids, and in the second – using Nessler’s reagent. Nitrate nitrogen was determined by ion-selective method using an EM-NO3-01 membrane electrode (Bobacka, 2006). The content of suspended solids (seston) was determined according to the gravimetric method with the use of membrane filters, which is

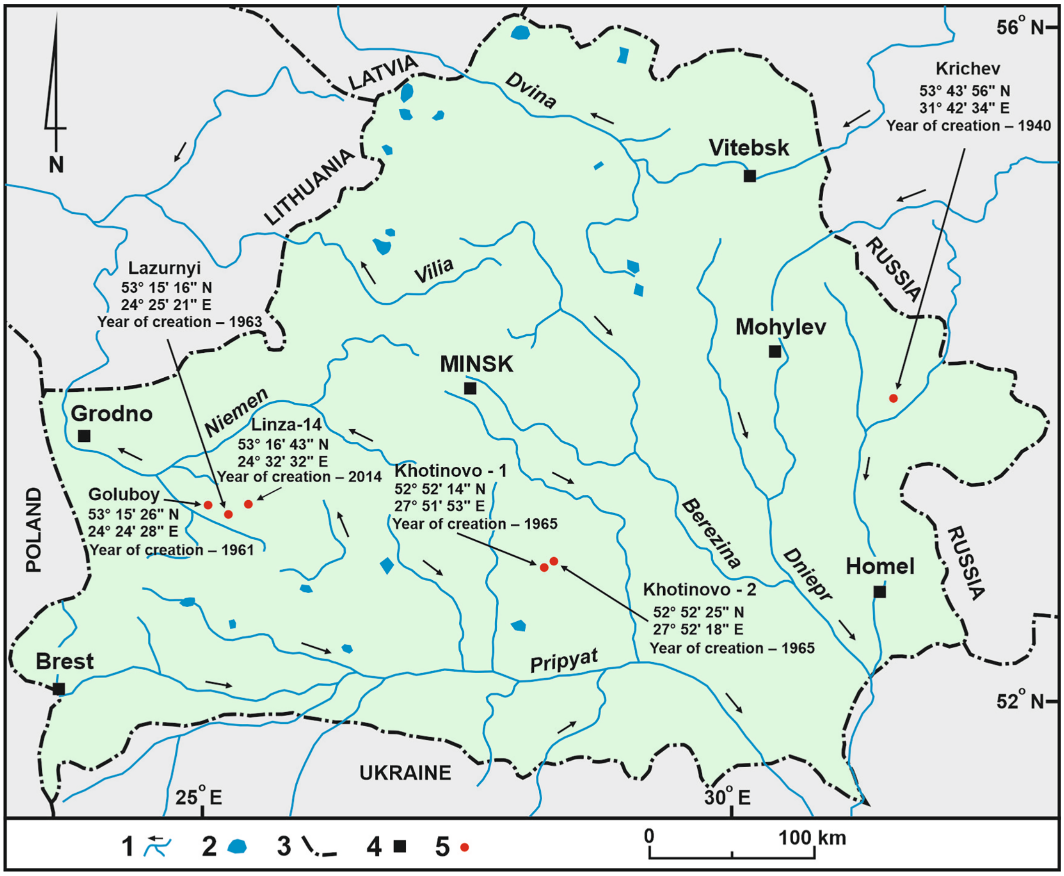

Fig. 1. Location of research area: 1 – watercourses, 2 – water bodies, 3 – state borders, 4 – major towns, 5 – investigated chalk quarry reservoirs.

generally accepted in hydro-biological studies. Sampling and laboratory-based studies of phytoplankton were performed according to methods generally accepted in hydrobiology (Makarevich and Savich, 2014; Wetzel, 2001; Lampert and Sommer, 2007).

Water samples for determining the content of seston, chlorophyll and for studying phytoplankton were taken using a two-litre Ruttner sampler (V = 2 l) at coastal stations from a depth of 0.5 m, and in the deep-water part of the reservoirs from surface (0.5 m) and bottom horizons, as well as from depths corresponding to one and two transparencies according to the Secchi disk. Phytoplankton was concentrated through settling. The volume for settling was 0.5 L. Utermöl's solution was used as a fixative used by many researchers for this type of tasks (Temporetti et al., 2001; Kong et al., 2016).

The content of seston was determined gravimetrically. Seston was concentrated on Nucleopor filters with a pore diameter of 1.5 μm, and dried to constant weight at a temperature of 70 °C. Chlorophyll *a* content (without the correction for phaeopigments) was determined on the same filters using the spectrophotometric technique with pigment extraction in 90% acetone (Kovalevskaya et al., 2020).

Phytoplankton samples ($V = 0.5$ dm^3) were fixed with Utermöhl's solution and concentrated using the settling method (Mikheyeva, 1989; Karlson et al., 2010). Phytoplankton was analysed using a Zeiss Axiolab light microscope, at a magnification of ×100, ×400, and ×1000. The abundance of algae was determined using a Fuchs-Rosenthal counting chamber (V = 3.2 mm^3). The abundance was expressed in the number of cells in 1 dm^3 (the number of unicellular organisms, cells in filaments and colonies), as well as in the number of organisms in 1 dm^3 (the number of unicellular organisms, colonies and filaments). In each sample, 200–400 organisms were counted to achieve a statistical error of no more than 20%.

Phytoplankton biomass was determined by the "true volume" method (Kiselev, 1969). This method is commonly used in this type of research (Popovskaya, 2000; Zeder et al., 2011; Bashenkhaeva et al., 2015; Obolkin et al., 2019) The essence of the method is as follows: when the abundance is calculated, the parameters of the cell (or organism) of each algae species are measured; the cell (organism) is equated to a certain geometric figure that most closely matches its shape; and bio-volume and biomass are calculated (the relative density of phytoplankton was set to 1).

To determine the species of algae, the keys of the series "Süßwasserflora von Mitteleuropa" as well as separate issues of the series "Das Phytoplankton des Süßwasser" and "Key to freshwater algae of the USSR" were used (Palamar-Mordvintseva, 1982).

To calculate the bio-productive and hydrochemical characteristics of quarry reservoirs based on the morphometric parameters of the water-bearing basins, the technique proposed by Romanov (1989) was applied, which is based on the use of a statistically significant inverse relationship between the morphometric specificity of the Sτ epilimnion and transparency. The revealed dependence allows calculating the potential transparency of the designed reservoirs and a number of potential productivity indicators correlating with it. The index of morphometric specificity of the Sτ epilimnion is calculated by the formula:

$$S\tau = \frac{1}{h_{cp}} \frac{1-(1-U)^2}{1-(1-U)^{\alpha+1}} \tag{1}$$

where h_{av} is the average depth of the future reservoir; U is the relative depth determined as $U = \frac{\tau}{h}$, where τ is the depth of the epilimnion, h is the maximum depth of the reservoir; $\alpha = \frac{h - h_{av}}{h_{av}}$.

The relationship between transparency and epilimnion index is described by the regression equation:

$$y = 0,79 \cdot x^{-0,74} \tag{2}$$

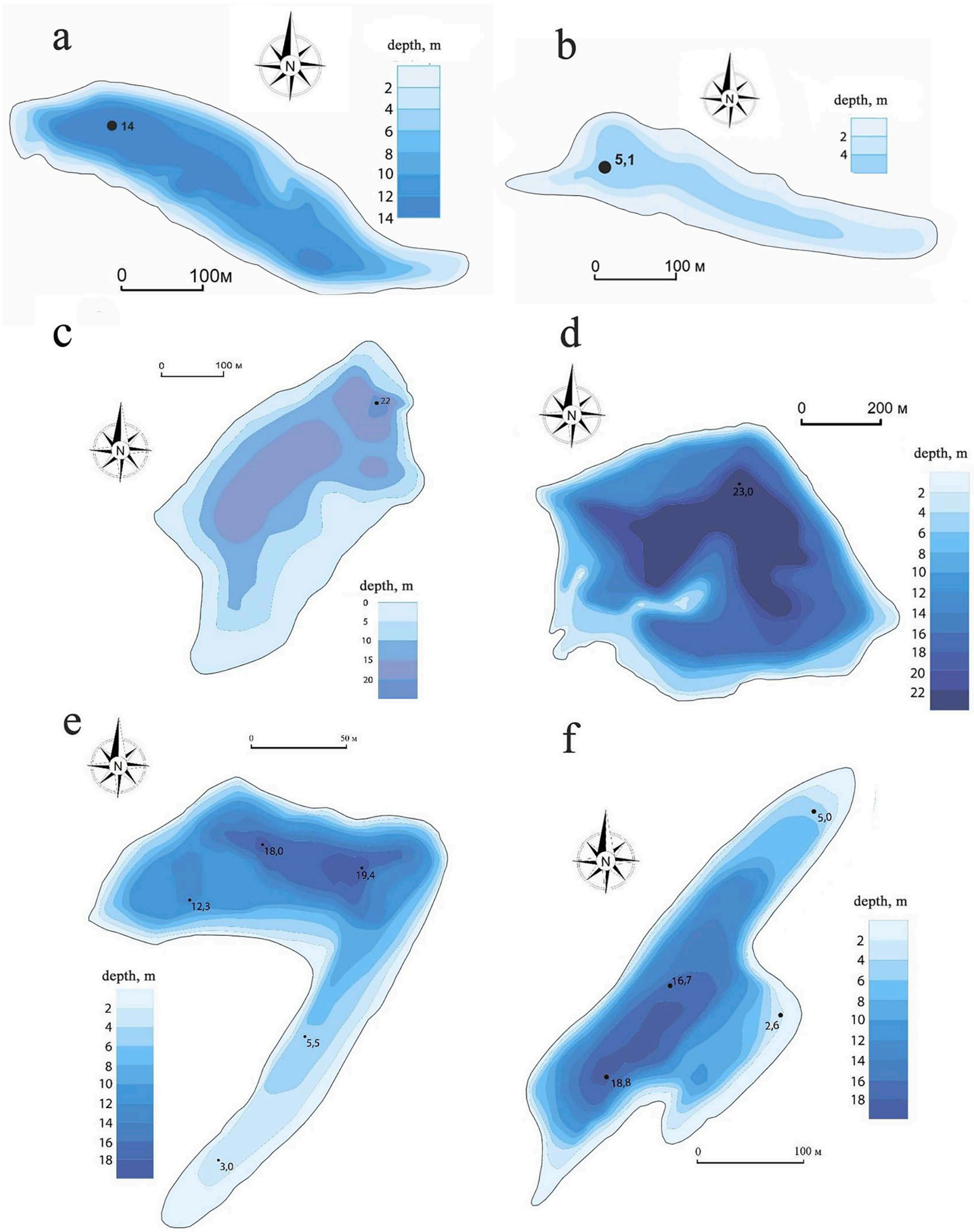

Fig. 2. Bathymetric plan of chalk quarry reservoirs in Belarus: a – Goluboy, b – Lazurnyi, c – Linza-14, d – Krichev, e – Khotinovo-2, f – Khotinovo-1.

The increase in transparency, in turn, correlates with other bio-productive indicators:

dichromate oxidation:

$$y = 39,63 \cdot x^{-0,352} \tag{3}$$

permanganate oxidation:

$$y = 10,76 \cdot x^{-0,455} \tag{4}$$

biochemical oxygen consumption (BOD_5):

$$y = 3,18 \cdot x^{-0,798} \tag{5}$$

colouration:

$$y = 38,28 \cdot x^{-0,383} \tag{6}$$

phytoplankton biomass:

$$y = 6,65 \cdot x^{-1,281} \tag{7}$$

the abundance of phytoplankton:

$$y = 20,89 \cdot x^{-1,382} \tag{8}$$

Presents the comparison of actual and potential bio-productive indicators of chalk quarry ponds summarized by the calculation of indicators of ecological sustainability of chalk quarry reservoirs: eutrophication level E, productivity index K (Tijdor, 1983; 1984), and eutrophication gradient D (E/K ratio), which is developed specifically for the of water reclamation sites (Khomitch, 2002b) and which characterizes the capacity of aquatic systems to increase trophic status. It is proposed to consider the gradient of eutrophication of reservoirs of

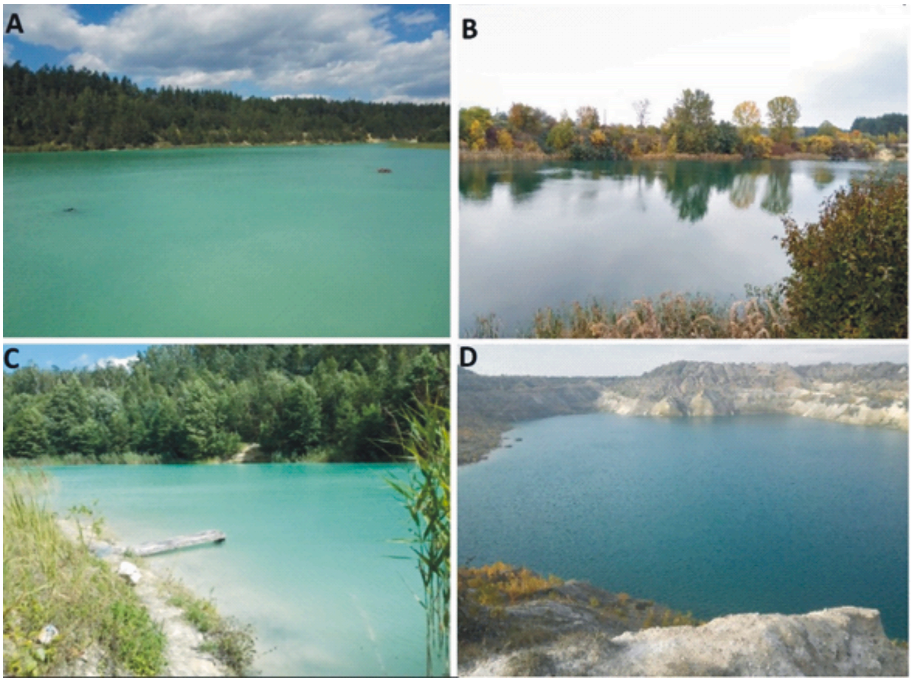

Fig. 3. The investigated chalk quarry reservoirs in Belarus (Photo by A. Ramanchuk): A – Khotinovo-1, B – Goluboy, C – Khotinovo-2, D – Linza-14.

productive-macrophyte type in a mesotrophic state equal to one ($D = E/K = 1$) as the unit of sustainability of water reclamation sites. The eutrophication level is calculated by the formula $E = \alpha \cdot T \cdot [CO_2], \cdot [O_2]$, the rate of the eutrophication process is calculated as the productivity index using the formula: where α is the coefficient that takes into account the presence of energetically active impurities in the reservoir; T is the temperature; CO_2, O_2 is the content of carbon dioxide and oxygen, and Q is the content of organic matter by dichromate oxidation. To characterize the ability of the system to increase the level of trophic status and assess the resistance of quarry reservoirs to eutrophication, the eutrophication gradient D was used, which reflects the ratio of the energy index E to the productivity index K.

3. Results

For the studied six chalk (limestone) quarry ponds in Belarus, the potential values of bio-productive indicators were calculated using the above dependences, and presented in Tables 2-5 in comparison with similar indicators obtained during field studies.

The potential transparency calculated using the index of morphometric specificity of the basins is proposed to be used in relation to the actual transparency as an express indicator that diagnoses the trophic status and type of productive structure of the quarry reservoir. Studies show that the ratio of actual transparency to predicted potential transparency, which exceeds 1, reflects the leading role of submerged macrophytes in the production of organic matter (Khomitch, 1996). The ratio of the actual transparency to the estimated one <1 indicates the predominance of phytoplankton in the processes of photosynthesis. Among the studied water-flooded chalk quarries, the Khotinovo-1 reservoir was the most highly transparent macrophyte reservoir. The potential transparency in this reservoir is 3.99 m, while the actual transparency provided by the barrier function of submerged macrophytes reaches 9 m. The actual transparency values in the reservoirs of Krichev, Khotinovo-2 and Linza-14 are above the estimated (predicted) transparency values. The ratio of actual to potential transparency varies from 1.03 in the youngest, with not yet formed macrophyte belt, flooded quarry of Linza-14 – to 1.54 in the quarry reservoir of Khotinovo-2. The established excess of the actual transparency of reservoirs, provided by bio-productive processes, over the predicted transparency, calculated from the morphometric parameters of quarries, indicates the production of organic matter mainly due to submerged macrophytes and effective interception and isolation of eutrophying substances in the tissues of higher aquatic plants. The productive-macrophyte orientation, natural mechanisms of phytomediation of the eutrophication process and low trophic status of the above-mentioned quarry ponds are also confirmed by the data on the content of phosphorus, nitrogen, and seston compounds in the surface and bottom waters (Khomitch et al., 2019), as well as the results of the study of phytoplankton and the evaluation of the chlorophyll content (Tables 2-5). The values of abundance and biomass of phytoplankton in the quarry reservoirs of Khotinovo-1, Khotinovo-2, and Linza-14 are close to the values characteristic of oligotrophic ponds. The structure of phytoplankton communities, with the exception of the bottom layers, is dominated by golden and cryptophytic algae, which is characteristic of reservoirs with a low level of trophia (Wetzel, 2001). The level of quantitative development of phytoplankton, species structure, and dimensional characteristics of algae in the Goluboy reservoir indicate a higher level of organic matter production by phytoplankton.

Data on the abundance, biomass, and species structure of phytoplankton, collected during the summer growing season, confirm the aforementioned productive-macrophyte orientation of the studied ponds and allow us to conclude about the high rate of succession processes in the newly formed chalk aquatic systems.

4. Discussion of the results

The technogenic origin of the basins of chalk ponds provides an opportunity, at the stages of mining and technical reclamation and arrangement of the water-bearing basin, to purposefully influence the hydrodynamic and bio-productive processes of potential water reclamation sites (Xu et al., 2020; Worlanyo and Jiangfeng, 2021). And within the framework determined by the morphology of the basin, the natural process of ecosystem development is taking place: a productive-functional structure of a certain type and mechanisms of resistance to eutrophying influences are formed. The basis of the defining relationship between the morphology of the basin and the bio-productive characteristics of the chalk ponds is the density, temperature,

Table 1
Morphometric parameters of chalk open-pit basins.

Quarry reservoirs	Reservoir area, hectares	Drainage area, hectares	Indicator of the morphometric specificity of the epilimnion	Volume of water mass, mln m^3	Length of the reservoir, m	Maximum width of the reservoir, m	Average width of the reservoir, m	Shoreline length, m	Coefficient of angularity of the coastline“	Maximum depth of the reservoir, m	Average depth of the reservoir, m	Elongation of the reservoir, m	Reservoir capacity	Shallow water area (up to 2 m)		Transparency during the observation period (actual)	Potential transparency, m	The ratio of actual transparency to the potential
														hectares	%			
Krichev[1]	37.67	313.0	0.05	4.412	975.0	725.0	386.85	2650.0	1.22	23.0	11.71	1.34	0.51	2.03	5.4	6.8	4.7	1.44
Goluboy [1,2]	5.40	167.0	0.06	0.456	580.0	164.0	93.19	1250.0	1.44	14.0	8.44	3.54	0.60	0.40	7.4	2.3	4.2	0.54
Lazurnyi [1]	4.90	151.0	0.27	0.086	410.0	98.0	55.81	920.0	1.72	5.1	3.75	4.18	0.74	2.64	53.9	1.4	1.4	1.0
Khotinovo-1[2]	4.57	150.0	0.112	0.394	470.0	180.0	108.51	1230.0	1.54	18.8	7.70	4.30	0.41	0.83	16.2	9.0	3.99	2.25
Khotinovo-2[2]	2.22	90.0	0.119	0.169	380.0	120.0	65.78	900.0	1.61	19.4	6.70	5.40	0.34	0.39	15.6	5.9	3.81	1.54
Linza-14[2]	12.57	–	0.09	1.130	590.0	280.0	213.05	1540.0	1.23	22.0	8.90	2.76	0.40	0.85	6.7	4.8	4.69	1.03

Explanations: (–) – lack of data; [1]Khomitch, 2001; Khomitch, 2002a; 2002b; [2]Authors' own data.

chemical and biological heterogeneity – stratification of the water mass. The naturalisation of such reservoirs most often occurs through spontaneous processes that make them similar to natural lakes (Mazur and Chmielowski, 2020). This is evidenced, among other things, by the emergence of natural thermal and oxygen patterns in the water bodies that have emerged in former mineral workings (Ramstedt et al., 2003; Castendyk and Eary, 2009).

Goluboy is the only (among the studied) chalk quarry reservoir with a ratio of actual to estimated transparency <1 (0.54). Since the very beginning of its existence, this reservoir has experienced a significant anthropogenic impact from the catchment area occupied by allotment garden plots. The finally unformed productive-macrophyte structure of the newly created quarry reservoir Goluboy could not effectively resist the processes of anthropogenic eutrophication. The area of littoral shallow waters in the unprepared open pit-basin did not exceed 0.40 ha and was inhabited only by individual colonies of *Elodea canadensis*, whose tissues were significantly oversaturated with compounds of nitrogen (0.44–0.96% of absolutely dry matter) and phosphorus (2.35–3.12% of absolutely dry matter) (Khomitch, 2002a; 2002b), which exceeds manifold the critical values of the content of these nutrients in the tissues of higher aquatic plants (N>=1.3%, P>=0.3% of absolutely dry matter) (Pokrovskaya et al., 1983; Demars and Edwards, 2008). Similar environmental conditions are preferred especially by the *Elodea canadensis* species mentioned above, as studies of other aquatic environments in Europe and Asia have reported (Hussner, 2012; Pomazkina et al., 2012; Poulis and Zervas, 2017). The insignificant littoral area, low projective cover of submerged macrophytes, and oversaturation of their tissues with nitrogen and phosphorus compounds did not allow higher aquatic vegetation to take leading positions in the Goluboy quarry reservoir and perform a barrier function. The priority role of phytoplankton in the production of organic matter in this pond and its high trophic status are confirmed by the data on the high content of phosphorus compounds in the surface and bottom water layers, as well as the high content of seston (Tables 2 and 5). In eutrophic environments, floating-leaved vegetation species are most common, which occur over large areas. A decisive role in this respect is attributed to the bottom morphology of water bodies and adequate water depth (Penning et al., 2008; Kolada, 2014; Lawniczak-Malińska et al., 2018). In contrast, under controlled nutrient enrichment conditions in oligotrophic limnic environments, similar relationships were observed with respect to the role of phytoplankton in increasing the amount of organic matter (Persson et al., 2008).

The trophic status of the studied reservoirs was monitored, in addition to the energy indicators of environmental sustainability, also by the data obtained during the field studies in 2018 on the content of seston and chlorophyll in the collected samples (see Figs. 4 and 5). High levels of seston in the Linza-14 and Goluboy reservoirs are determined by the initial stage of the succession process and are indicative of the high trophic status of the macrophyte-eutrophic reservoir Goluboy. In terms of the chlorophyll content, a similar vertical distribution of this indicator was recorded: the maximum chlorophyll content was recorded in the tropholytic layer of the Linza-14 and Goluboy reservoirs. Similar values are characteristic of deep oligotrophic lakes (Padisák et al., 1997) and were also periodically found in a shallow lake which exhibited significant seasonal variations (Dembowska et al., 2018). The algorithm for calculating the potential bio-productive characteristics of quarry reservoirs using the morphometric specificity index of the epilimnion is presented in Fig. 4.

Using R.E. Tiidor's energy indicators, it was proposed to assess the current trophic state of chalk reservoirs (level, productivity index and gradient of eutrophication). It is proposed to diagnose the prospects for the functioning of chalk quarry reservoirs in terms of their tourist and recreational use on the basis of the identified type and stage of development of the productive-trophic structure of the reservoir. Comprehensive limnological studies of the structural and functional characteristics of quarry ponds indicate two main ways of development

Table 2
Phytoplankton community structure in quarry reservoirs of chalk deposits, 7.10–4.11.2018.

Reservoir/station, depth	Number (N)		Biomass (B)		I, cell./org.	$V_{av.}$, µm^3
	N_{total}, mln org./dm^3	dominant group, % N_{total}	B_{total}, mg/dm^3	dominant group, % B_{total}		
Khotinovo-1 by the coast, 0.5 m	1.020	*Chrysophyta* – 52.4; *Cryptophyta* – 20.1; *Chlorophyta* – 10.4	0.174	*Chrysophyta* – 37.9; *Cryptophyta* – 27.4; *Dinophyta* – 12.9; *Cyanobacteria* – 12.4	4.2	40.4
canter, 0.5 m	0,836	*Chrysophyta* – 72.7; *Cryptophyta* – 20.3	0.124	*Chrysophyta* – 54.9; *Cryptophyta* – 32.6; *Dinophyta* – 10.3	1.6	94.7
canter, 4.5 m	1.350	*Chrysophyta* – 63.5; *Cryptophyta* – 14.6; *Cyanobacteria* – 10.4	0.180	*Chrysophyta* – 52.4; *Cryptophyta* – 22.0; *Cyanobacteria* – 15.8	4.4	30.3
canter, 9.0 m	2.153	*Chrysophyta* – 56.5; *Cryptophyta* – 19.6; *Cyanobacteria* – 10.1	0.315	*Chrysophyta* – 52.5; *Cryptophyta* – 26.8	3.4	43.2
canter, 17.0 m	1.050	*Cyanobacteria* – 85.0	0.306	*Cyanobacteria* – 48.8; *Euglenophyta* – 33.1; *Cryptophyta* – 15.0	16.5	17.7
Khotinovo-2 by the coast, 0.5 m	1,199	*Chrysophyta* – 72.3; *Cryptophyta* – 16.0	0.230	*Chrysophyta* – 59.7; *Cryptophyta* – 21.6	2.2	86.5
canter, 0.5 m	1.672	*Chrysophyta* – 81.4	0.317	*Chrysophyta* – 41.7; *Cryptophyta* – 36.6; *Euglenophyta* – 15.0	1.2	152.9
canter, 6.0 m	1.319	*Chrysophyta* – 65.2; *Cryptophyta* – 25.0	0.306	*Chrysophyta* – 51.2; *Cryptophyta* – 34.3; *Chlorophyta* – 11.1	2.3	101.2
canter,12.0 m	0.189	*Cryptophyta* – 37.8; *Chlorophyta* – 20.6; *Bacillariophyta* – 17.2; *Chrysophyta* – 13.8	0.093	*Cryptophyta* – 60.5; *Dinophyta* – 19.6	1.1	448.8
canter, 18.0 m	0.752	*Cyanobacteria* – 85.1	0.075	*Cyanobacteria* – 52.2; *Chlorophyta* – 22.7; *Chrysophyta* – 12.9; *Bacillariophyta* – 11.1	6.7	15.0
Linza-14 by the coast, 0.5 m	4.534	*Chrysophyta* – 69.4; *Bacillariophyta* – 11.8; *Cryptophyta* – 10.8	1.333	*Chrysophyta* – 42.7; *Cryptophyta* – 26.7; *Dinophyta* – 17.1	1.8	159.9
canter, 0.5 m	4. 279	*Chrysophyta* – 64.1; *Chlorophyta* – 10.8	0.886	*Chrysophyta* – 50.3; *Dinophyta* – 20.7; *Cryptophyta* – 16.0	1.4	144.1
canter, 5.0 m	4. 085	*Chrysophyta* – 66.1; *Bacillariophyta* – 10.1; *Cryptophyta* – 10.1	1.801	*Dinophyta* – 32.1; *Cryptophyta* – 30.6; *Chrysophyta* – 27.1	1.3	328.2
canter, 10.0 m	4.316	*Chrysophyta* – 73.2; *Cryptophyta* – 10.7	1.270	*Chrysophyta* – 50.2; *Dinophyta* – 22.3; *Cryptophyta* – 19.7	1.9	154.4
canter, 16.0 m	1.122	*Cryptophyta* – 59.4; *Cyanobacteria* – 15.6; *Chrysophyta* – 13.5	1.133	*Cryptophyta* – 88.6	8.8	114.3
Lazurnyiby the coast, 0.5 m	3.234	*Bacillariophyta* – 29.0; *Cyanobacteria* – 23.7; *Chrysophyta* – 16.4; *Cryptophyta* – 13.5; *Euglenophyta* – 10.6	0.972	*Bacillariophyta* – 31.1; *Dinophyta* – 16.4; *Euglenophyta* – 13.8; *Cryptophyta* – 13.1; *Chlorophyta* – 10.2	3.7	82.3
Goluboyby the coast, 0.5 m	4.859	*Bacillariophyta* – 48.5; *Chrysophyta* – 19.5; *Chlorophyta* – 16.0	0.763	*Bacillariophyta* – 37.5; *Cyanobacteria* – 20.6; *Chlorophyta* – 15.9; *Chrysophyta* – 13.4; *Cryptophyta* – 11.3	4.0	39.4
canter, 0.5 m	7.149	*Bacillariophyta* – 51.0; *Chrysophyta* – 32.9	1.363	*Bacillariophyta* – 34.2; *Chrysophyta* – 27.7; *Dinophyta* – 15.1	2.9	65.4
canter, 4.0 m	8.643	*Bacillariophyta* – 46.8; *Chrysophyta* – 36.0	1.267	*Bacillariophyta* – 40.5; *Chrysophyta* – 16.0; *Dinophyta* – 12.7; *Chlorophyta* – 10.9; *Cyanobacteria* – 10.0	3.3	43.8
canter, 8.0 m	7.324	*Bacillariophyta* – 58.6; *Chrysophyta* – 15.2; *Chlorophyta* – 12.9	1.193	*Bacillariophyta* – 43.5; *Chlorophyta* – 15.0; *Dinophyta* – 13.4	2.1	77.9
canter, 12.0 m	20.612	*Cyanobacteria* – 67.4; *Bacillariophyta* – 19.1	1.199	*Bacillariophyta* – 44.0; *Chlorophyta* – 17.4; *Cryptophyta* – 16.4; *Cyanobacteria* – 11.3	1.7	33.6

Note:
I – indicator of the degree of colonial characteristics of phytoplankton organisms;
V – average volume of a planktonic cell.

of water reclamation sites: productive-macrophytes and productive-phytoplankton, which differ in the level of resistance of reservoirs to external and internal eutrophying influences, the duration of the period of natural and economic optimum (Fig. 5). The validity of this type of inference is demonstrated by the research that was conducted slightly earlier in this respect (Khomitch et al., 2019). Recently, there has been an increasing number of examples where water bodies in former quarries in different parts of the world have found tourist and recreational uses (Doupé and Lymbery, 2005; Kalybekov et al., 2019).

For macrophyte reservoirs, three stages of productive-functional structure development are distinguished: potentially macrophyte, actually macrophyte, and residual macrophyte. It is proposed to diagnose stage transitions of productive-macrophyte systems by the content of nitrogen and phosphorus compounds in the tissues of submerged macrophytes. Reservoirs of phytoplankton orientation go through only one productive-phytoplankton stage. Phytoplankton is the leading producer of organic matter throughout the entire period of the reservoir development. The reservoir responds to the inflow of eutrophying substances in accordance with the classical concept of eutrophication – an increase in phytoplankton productivity, a decrease in transparency, an increase in the content of biogenic elements (nutrients) in waters and bottom sediments, and a transition from a low-trophic state to a high-trophic state (Khomitch, 2002a). Such changes in the fertility of limnic waters, both in lakes and artificial water bodies, are a common occurrence (Rast and Thornton, 1996; Kim et al., 2001; Qin et al., 2006; Callisto et al., 2014; Yu et al., 2019). The evolutionary of development schemes for various types of quarry reservoirs make it possible to determine the current state of newly formed aquatic systems, and to characterize the trends and prospects of their further development. Productive and trophic states of quarry ponds include the characteristics of the leading producer of organic matter and the trophic status of the reservoir (macrophyte-mesotrophic, macrophyte-eutrophic, etc.). Stage transitions can be tested by the results of tissue analysis of submerged macrophytes, as well as using the eutrophication gradient D (the ratio of the energy index E to the productivity index K).

Prosperous conditions of macrophyte reservoirs during the period of natural and economic optimum (up to the “sustainability threshold”) are provided by the perfect mechanism of sustainability of the productive-

Table 3
Content of seston and chlorophyll in the water of quarry reservoirs of chalk deposits, 7.10–4.11.2018. Average values are given ± SD.

Reservoir/station, depth	Seston, mg/dm^3	Chlorophyll-a	
		μg/dm^3	% in seston
Khotinovo-1,			
centre, 0.5 m	0.91 ± 0.04	0.42 ± 0.02	0.05 ± 0.00
centre, 4.5 m	0.52 ± 0.04	0.52 ± 0.02	0.10 ± 0.01
centre, 9 m	0.50 ± 0.07	0.54 ± 0.03	0.11 ± 0.02
centre, 17 m (near-bottom layer)	1.33 ± 0.33	1.73 ± 0.05	0.13 ± 0.03
Khotinovo-2			
centre, 0.5 m	0.73 ± 0.06	0.84 ± 0.02	0.12 ± 0.01
centre, 6.0 m	0.45 ± 0.04	1.45 ± 0.08	0.32 ± 0.02
centre, 12.0 m	3.38 ± 0.08	1.62 ± 0.08	0.05 ± 0.00
centre, 18.0 m	4.67 ± 0.29	4.06 ± 0.17	0.09 ± 0.01
Linza-14			
centre, 0.5 m	2.03 ± 0.15	1.97 ± 0.07	0.10 ± 0.00
centre, 5.0 m	1.64 ± 0.05	1.83 ± 0.13	0.11 ± 0.01
centre, 10.0 m	1.33 ± 0.16	1.80 ± 0.23	0.14 ± 0.02
centre, 16.0 m	2.71 ± 0.00	3.04 ± 0.25	0.11 ± 0.01
Goluboy			
centre, 0.5 m	1.29 ± 0.07	1.39 ± 0.02	0.11 ± 0.01
centre, 4.0 m	1.33 ± 0.07	1.49 ± 0.06	0.11 ± 0.00
centre, 8.0 m	1.29 ± 0.00	1.71 ± 0.13	0.13 ± 0.01
centre, 12.0 m	5.56 ± 0.19	9.46 ± 0.65	0.17 ± 0.01

Table 4
Phytoplankton community structure in quarry reservoirs of chalk deposits, 17–24.07.2012. Coastal stations, depth – 0.5 m.

Reservoir	Number		Biomass	
	N_{total}, mln org./dm^3	dominant group, % N_{total}	B_{total} mg/dm^3	dominant group, % B_{total}
Khotinovo-2	2.77	*Chlorophyta* – 25.4; *Chrysophyta* – 18.5	1.15	*Chlorophyta* – 32.7; *Chrysophyta* – 17.4
Linza-14	0.845	*Chlorophyta* – 35.7; *Chrysophyta* – 21.6	0.49	*Chrysophyta* – 76.3
Lazurnyi	3.405	*Bacillariophyta* –56.6; *Cryptophyta* –13.7	0.58	*Bacillariophyta* – 47.6; *Cryptophyta* –17.9
Goluboy	6.574	*Chlorophyta* – 49.2; *Bacillariophyta* – 24.9	2.38	*Chlorophyta* –78.7

macrophytes system. The use of the model “morphological parameters of the host basin – bio-productive indicators” and the analysis of potential productive capacity of the reservoir are the basis for choosing the optimal way of reclamation; they determine the expediency of tourist and recreational development of quarry reservoirs. In combining this approach to the study of prospects of quarry reservoirs with the above possibility of quantitative assessment of their condition (position within the evolutionary development), it is possible to purposefully form sustainably functioning macrophyte reservoirs and to control the process of trophic status. Calculation of potential indicators of the reservoir productivity, which is based on the accounting for man-caused morphometric characteristics, allows at the design stage of reservoirs to offer the optimal morphometric parameters of future open-pit quarries. The main task of geo-ecological design of water reclamation sites for tourist and recreational use is to ensure and maintain the newly formed aquatic system within its optimum with a gradient of eutrophication up to 4.0. The lower the eutrophication gradient, the more perfect the sustainability mechanism – the “immunity” of the reservoir to eutrophying influences.

An important morphometric prerequisite for the formation of productive-macrophyte structure of the reservoir is littoral shallow waters suitable for the development of submerged vegetation. Coastal shallow waters should have a gently sloping bottom. The substrate, which forms the littoral part of the reservoir, is also essential for the rooting of submerged vegetation. Extensive coastal shoals, characterized by a slow increase in depth and significant water transparency, are poorly acclimated by submerged macrophytes if their bottom is covered with large pebbles, stones, or is exposed to waves. The absence of coastal shallow waters prevents the spread of submerged macrophytes. As a result, nutrients coming from the catchment and not encountering a protective barrier in their path become available to the phytoplankton community. Among the morphometric conditions, which also do not contribute to the rapid introduction of submerged vegetation in the reservoir, is the large openness of lake basins, which determines the intense wind-wave mixing and active shoreline erosion. Certain species of submerged macrophytes with a wide ecological amplitude (*Potamogeton perfoliatus*) can acclimate such littoral areas (Mäemets et al., 2006; Ailstock et al., 2010).

The man-caused origin of the basins of quarry reservoirs makes it possible to recommend technically feasible, economically and ecologically sound measures for the creation of an aquatic system with productive-macrophyte orientation already at the stage of transformation of a depleted quarry into a basin of the future reservoir. Preparing a quarry reservoir basin, dredging operations, obligatory backfilling of the littoral area, which should account for up to 5–10% of the water area, fixing the surface part of the slopes and shores of the reservoir, which prevents landslides, aligning the coast – all these arrangements, taking into account the dependencies inherent in limnic systems, are designed to contribute to the purposeful formation of a macrophyte reservoir. The possibility of calculating potential indicators of reservoir productivity based on man-caused morphometric characteristics ensures the development and incorporation into the water reclamation project of the optimal parameters of water-bearing basins, contributing to the long-term, sustainable functioning of the newly formed aquatic systems. The main scope of work on the transformation of various types of quarries workings into lake basins with specified parameters includes the following activities carried out in the process of mining and engineering reclamation:

- backfilling of the coastal shallow water zone (up to a depth of 2.0 m, the underwater part of the slope should have the horizontal equivalent of 1:2) to populate the reservoir with submerged macrophytes The size of the littoral area should be at least 10–25% of the water area;
- dredging operations that increase the water mass volume (and hence the inertial properties of the reservoir) without increasing the aquatic area. When designing and carrying out dredging operations, it should be taken into consideration that the optimal shape of the basin, which provides stratification of the water mass and its stability, is a shape similar to a cylinder or semi-ellipsoid. The ratio between the average and maximum depths – the regular coefficient – in this case should vary from 0.66 to 1 (Yakushko, 1981). The question of the presence of stratification and its stability is of particular importance. With a minor influx of biogenic elements (nutrients) with surface runoff, stratification drastically limits the productive capacity of phytoplankton and creates favourable conditions for the development of submerged macrophytes;
- formation of beach areas by flattening the open-pit sides (the slope is 1:3 in the area extending from the water’s edge to the mark of 1 m above the maximum water level);
- consolidation of the upper part of the shores, which prevents the development of landslides leading to the destruction of submerged macrophytes that colonize the reservoir;
- alignment of the shoreline aimed at eliminating stagnant “inlets” characterized by unfavourable gas conditions, a significant spread of filamentous algae, which have a negative impact on the bioproductive regime of the reservoir.

Research on innovative methods of reclamation of flooded chalk pits

Table 5
Morphometric, physical–chemical and bio-productive indicators of chalk quarries.

Indicators	Krichev	Goluboy	Lazurnyi	Khotinovo-1	Khotinovo-2	Linza-14
Morphometric indicators of open-pit basins						
Deptth of the reservoir, m:						
maximum	23.0	14.0	5.10	18.8	19.4	22.0
average	11.71	8.44	3.75	7.70	6.70	8.90
Area of:						
reservoir, hectares	37.67	5.40	4.90	4.57	4.22	12.57
littoral area %	5.4	7.4	53.9	16.2	15.6	6.7
Indicator of morphometric						
specificity of epilimnion, Sτ	0.050	0.060	0.270	0.112	0.119	0.090
Potential and actual bio-productive indicators						
Transparency, m:						
potential	4.7	4.2	1.4	3.99	3.81	4.69
actual (observed)	6.8	2.3	1.3	9.0	5.9	4.8
average actual	4.5	3.0	1.2	–	–	–
Permanganate oxidation, mgO_2/ dm^3:						
actual	4.48	7.36	1.34	–	–	–
potential	5.32	5.66	9.23	–	–	–
Dichromate oxidation, mgO_2/dm^3:						
actual	20.13	29.56	–	–	–	–
potential	22.98	24.12	35.2	–	–	–
Colouration, degrees:						
actual	18	28	6	–	–	–
potential	21	22	34	–	–	–
BOD_5, mgO_2/l:						
actual	0.68	1.64	–	–	–	–
potential	0.92	1.03	2.43	–	–	–
Abundance						
of phytoplankton, mln cells/l:						
actual	0.53	4.79	0.11	–	–	–
potential	2.46	2.97	13.12	–	–	–
Biomass of phytoplankton, g/m^3:						
actual	0.49	1.46	0.14	–	–	–
potential	0.92	1.00	4.32	–	–	–
Polyphosphates (PO_4^{-3}), mg/dm^3:						
surface	–	0.05	–	0.03	<0.0001	0.01
bottom	–	0.07	–	0.01	0.02	<0.01
Phosphates, mg/dm^3:						
surface	0.0039	0.06	0.002	0.04	0.01	0.02
bottom	0.0052	0.11	0.004	0.03	0.07	0.02
Nitrates ($NO^-{}_3$), mg/dm^3:						
surface	0.24	0.20	0.05	0.14	0.20	0.60
bottom	0.26	0.60	0.04	0.23	0.29	0.30
Nitrite ($NO^-{}_2$), mg/dm^3:						
surface	0.137	0.01	0.0008	<0.01	<0.01	0.01
bottom	0.107	0.02	0.0031	<0.01	<0.01	0.01
Ammonium (NH_4^+), mg/dm^3:						
surface	0.42	<0.1	0.09	<0.1	<0.1	<0.1
bottom	0.34	<0.1	0.85	<0.1	<0.1	<0.1
Seston. mg/dm^3, average:						
surface	–	1.29	–	0.90	0.73	2.03
bottom	–	5.56	–	1.33	4.67	2.71
Environmental sustainability indicators						
Energy index						
(eutrophication level, E)	115.13	89.58	109.51	–	–	–
Productivity index						
(eutrophication rate, K)	54.15	19.87	11.16	–	–	–
Eutrophication gradient (D = E/K)	2.1	4.5	9.8	–	–	–

is in line with several sustainable development goals (https://sdgs.un.org/goals). Reclamation of water bodies through the introduction of macrophyte vegetation will ultimately make it possible to use flooded mineral workings as sources of high-quality water that can be used to supply the population with drinking water or as attractive places of waterfront recreation. On the other hand, the reclamation of water bodies in flooded chalk pits through the introduction of phytoplankton may offer opportunities for breeding fish and other aquatic organisms as well as the use of water for irrigation, e.g. of areas used for food production. Thus, the reclamation activities undertaken with respect to the type of water bodies in question may be considered primarily in line with the "Ensure availability and sustainable management of water and sanitation for all" Sustainable Development Goal, and in particular the following targets: "protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes", "expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies" and "support and strengthen the participation of local communities in improving water and sanitation management". The phytomediation methods proposed with respect to anthropogenic water bodies are also related to the achievement of the following sustainable development goals:

– "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss", especially in

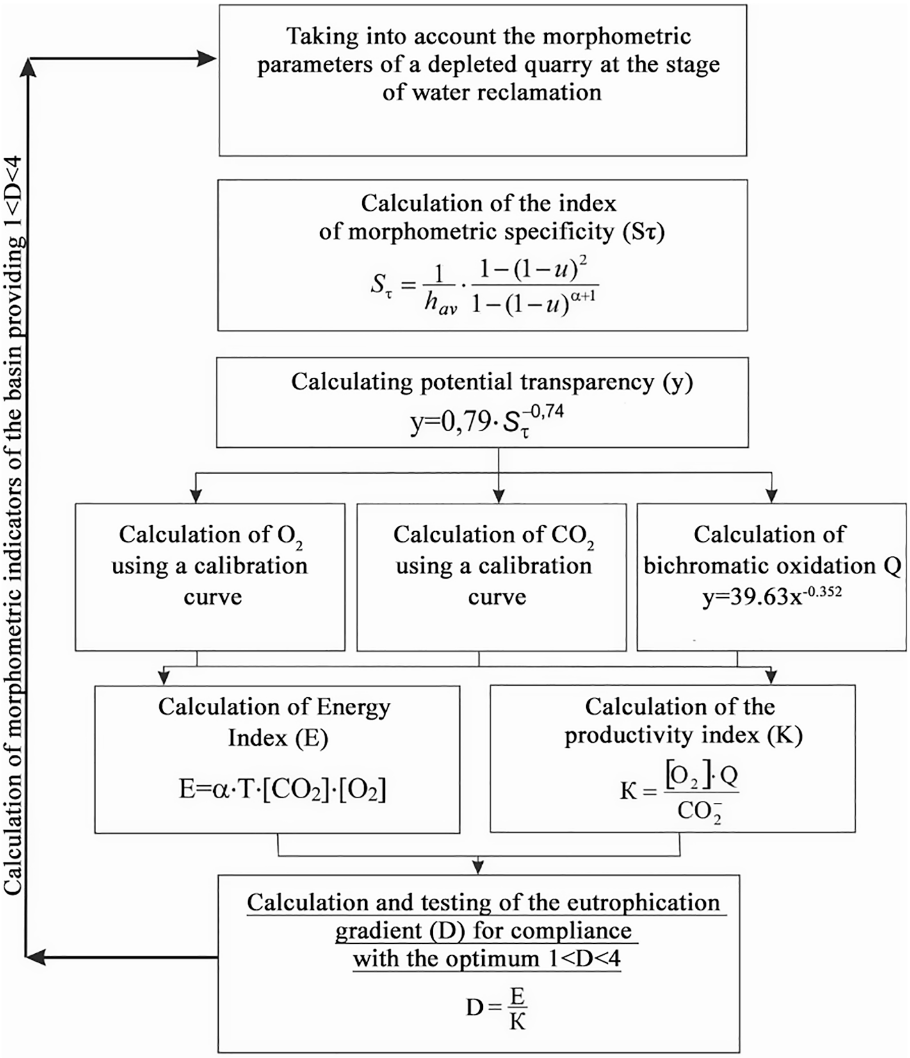

Fig. 4. Methodical approach to the assessment of potential bio-productive indicators and trophic status of chalk quarry reservoirs.

terms of addressing the effects of drought;

– “end hunger, achieve food security and improved nutrition and promote sustainable agriculture”.

5. Conclusions

To substantiate the possibility of creating ecologically sustainable lake-type aquatic systems on the site of the resource depleted chalk quarries, the morphometric parameters of technogenic quarries-basins and bio-productive characteristics of the water mass have been studied. A bathymetric survey was carried out, and the key morphometric parameters were calculated for the basins of six chalk quarry reservoirs in Belarus, which differ in area (2.22–37.67 ha), maximum depths (5.1–23.0 m) and the size of littoral shallow waters (0.39–2.64 ha). Hydrobiological indicators (abundance, biomass, species composition of phytoplankton, content of seston and chlorophyll) were obtained, which reflect differences in the productive-functional organization and trophic status (low-trophic – high-trophic).

The dependence of the productive-functional organization and trophic status of a quarry reservoir on the morphometric features of the technogenic basin is revealed. An algorithm is proposed for calculating the level (E), productivity index (K) and gradient of eutrophication (D) of chalk (limestone) quarry reservoirs using the morphometric specificity indicator of the trophogenic epilimnial layer (Sτ – 0.05–0.270). Potential indicators (determined by morphometric parameters of the basin) of the level (E – 89.58–115.13), productivity index (K – 11.16–54.15) and gradient of eutrophication (D – 2.1–9.8) of the studied chalk open-pit reservoirs are calculated, which reflect the capacity of the aquatic system to resist the increase in trophic status.

A comparative analysis of potential and actual (intrinsic) bio-productive indicators of the investigated chalk quarry reservoirs is carried out (eg. transparency – 1.2–6.8 m, phosphates – 0.002–0.110 mg/dm^3, nitrates – 0.040–0.600 mg NO^-_3/dm^3, biomass of phytoplankton – 0.075–1.801 mg/dm^3, seston – 0.73–5.56 mg/dm^3). All studied reservoirs are classified as productive-macrophyte aquatic systems. A high trophic status is recorded in the Krichev, Lazurnyi, and Goluboy reservoirs. The highest rate of eutrophication processes was found in the macrophyte-mesotrophic reservoir Krichev. But due to the perfect mechanisms of natural phytomedication, this quarry reservoir remains highly transparent and suitable for tourist and recreational use. The chalk quarry reservoirs Khotinovo-1 and Khotinovo-2 are classified as macrophyte slightly eutrophic water bodies with well-formed sustainability mechanisms.

The recently retired water-flooded chalk quarry Linza-14 is just forming its macrophyte-type productive and functional structure and is currently in the early stages of the successional process. A conclusion is made about the capacity of macrophyte quarry reservoirs to long-term preservation of their basic productive and trophic characteristics under conditions of anthropogenic impact. The initial management decision on the revitalization of chalk quarry-dump complexes is proposed

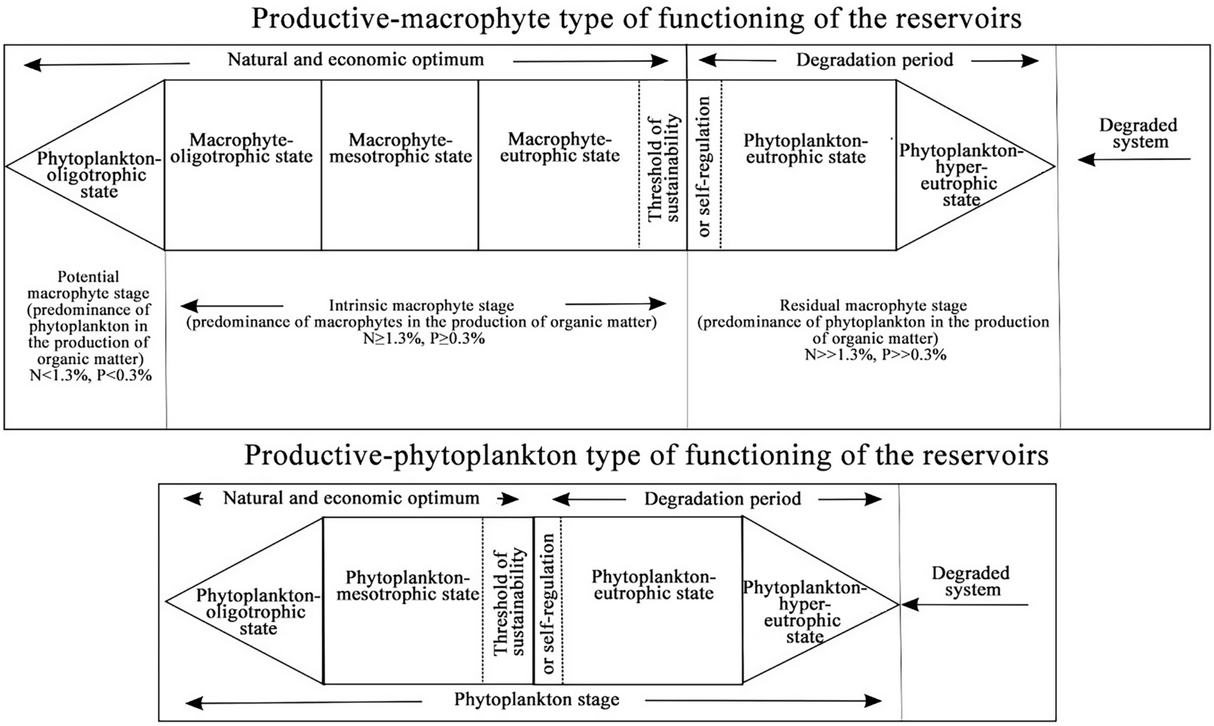

Fig. 5. Schemes of the evolutionary development of reservoirs of productive-macrophyte and productive-phytoplankton types.

to be the orientation of the formed reservoirs towards the creation of macrophyte productive systems capable of effective self-regulation, phytomediation of eutrophication processes and long-term sustainable existence in terms of their tourist and recreational use. The concept of managing chalk quarry aquatic complexes is to maintain the natural and man-caused aquatic system within the "potential optimum" (change in the eutrophication gradient from 1 to 4), which is provided in macrophyte reservoirs by the optimal morphometric parameters of opencast basins, the barrier function of submerged macrophytes, as well as by monitoring threshold bio-productive indicators.

Due to the determinative relationship between the morphology of man-caused water-bearing basins and the bio-productive specificity (identity) of reservoirs, the possibility of purposeful formation of the optimal macrophyte productive-functional structure of quarry reservoirs at the stage of mining and engineering reclamation is demonstrated. Calculation of the optimal parameters of opencast basins and corresponding potential values of the level, productivity index and gradient of eutrophication at the design stage of water reclamation sites in resource depleted chalk quarries can be considered as a key (starting) element of phytomediation of bio-productive processes. Research on innovative methods of reclamation of flooded chalk pits is in line with sustainable development goals.

CRediT authorship contribution statement

Aliaksei I. Ramanchuk: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Visualization, Project administration, Writing - review & editing. **Tamara A. Makarevich:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing - review & editing. **Svetlana Khomitch:** Conceptualization, Methodology, Validation, Investigation, Resources, Writing – original draft, Supervision, Project administration, Writing - review & editing. **Robert Machowski:** Conceptualization, Validation, Writing – original draft, Visualization, Writing - review & editing. **Martyna A. Rzetala:** Conceptualization, Validation, Visualization, Funding acquisition, Writing - review & editing. **Mariusz Rzetala:** Conceptualization, Methodology, Validation, Writing – original draft, Visualization, Supervision, Project administration, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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