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THE COOLING POND OF IGNALINA NPP AS A MODEL SYSTEM EVALUATING EFFECT OF RADIOACTIVE, CHEMICAL AND THERMAL POLLUTION TO AQUATIC PLANTS

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Abstract. The scope of this research included an evaluation of the influence of radioactive, thermal and chemical pollution on ecotoxicological state of Lake Drūkšiai – the cooling pond of Ignalina NPP during the long-term investigations (1988–2009). The accumulation of ^{137}Cs, ^{60}Co and ^{54}Mn in hydrophytes and bottom sediments of Lake Drūkšiai, as well as the determination of toxicity and genotoxicity of water and bottom sediments of monitoring stations of this Lake and the assessment of the impact of discharges of the Ignalina NPP on radioecological and ecotoxicological state of Lake Drūkšiai were performed. The standard radioecological and ecotoxicological methods were used performing these investigations. It was found that radioecological situation of Lake Drūkšiai after 1996 is quite good. The ecotoxicological situation of the Lake changed little during 1988–2009, however, in some cases tendencies of the toxicity increase in water and bottom sediments is observed. However, it may be claimed that toxic impact of water and bottom sediments of Lake Drūkšiai was caused more not by radioactive pollution, but by the total impact of various toxic substances. Investigations of thermal pollution impact on plants showed that thermal factor can influenced the physiological state of tested plants, consequently, the accumulation levels of radionuclides in plants and inner compartment of cells may be affected.

Keywords: accumulation, biological tests, Ignalina NPP, technogenic radionuclide, thermal pollution, toxicity.

1. Introduction

Radioecological and ecotoxicological investigations were carried out in Lake Drūkšiai – the cooling pond of the Ignalina Nuclear Power Plant (NPP). Lake Drūkšiai is the largest lake of Lithuania. This NPP is located near the Lithuanian border with Belarus and Latvia. Like Chernobyl NPP, Ignalina NPP was equipped by RBMK–1500 type reactors. Unit 1 was put into operation in 1984 and Unit 2 – in 1987. Unit 1 and Unit 2 were closed on 31 December, 2005 and 2009, respectively. Long-term investigations show that technogenic radionuclides, among which long-lived radionuclides are the most dangerous, constantly penetrate from the Ignalina NPP into Lake Drūkšiai (Marčiulionienė *et al.* 1992; Motiejūnas 1998).

Lake Drūkšiai had been impacted not only by a radioactive pollution, but also by chemical and thermal pollution. Tha waste water of the Ignalina NPP was mainly multicomponent mixtures of chemicals substances (biogenic elements, diluted weak organic acids, heavy metals, petrolic hydrocarbons and so on (Jokšas 1997; Marčiulionienė *et al*. 2001) which in most cases deposited in the bottom sediments of the lake.

Bottom sediments, which contain a large amount of organic matters, correctly represent a long–term radioecological state of the hydroecosystem, because they may become a medium for radionuclide deposition (Трапезников *et al.* 2007). Hydrophytes intensively concentrate radionuclide's occurring in the environment in micro amounts by assimilating them both from water and bottom sediments. Radionuclide activity concentrations in hydrophytes can be established comparatively accurately, even in cases, when their activity concentrations in other environmental components are under the minimal detectable level. Water is the least informative component for the assessment radioactive pollution of hydroecosystems, because radionuclides are quickly diluted and their activity concentration in water significantly decreases (Marčiulionienė *et al*. 2001).

The aim of this study was to determine accumulation of ^{137}Cs, ^{60}Co and ^{54}Mn in hydrophytes and bottom sediments of Lake Drūkšiai; to investigate the toxicyti and genotoxicity of water and bottom sediments of monitoring station of this Lake on plants and to assess the influence of discharges of Ignalina NPP on radioecological and ecotoxicological state of the Lake.

2. Materials and methods

Samples of hydrophytes, water and bottom sediments were collected in the monitoring Stations of Lake Drūkšiai in 1988–2009 (Fig 1). Radionuclide activity concentration in the hydrophytes and bottom sediments was estimated by the γ-spectroscopy methods (Gudelis *et al*. 2000). The values of radionuclide activity concentrations in the study are presented on the dry weight basis. Toxicity and genotoxicity tests of the water and bottom sediments were carried out based on the biological tests *Lepidium sativum* L. (garden-cress) and *Tradescantia* clone 02 (spiderwort) (Magone 1989; Montvydienė and Marčiulionienė 2004). The level of water and bottom sediments toxicity and genotoxicity to plants was assessed following the methods suggested by Wang (1992) and Osipova and Shevchenko (1984).

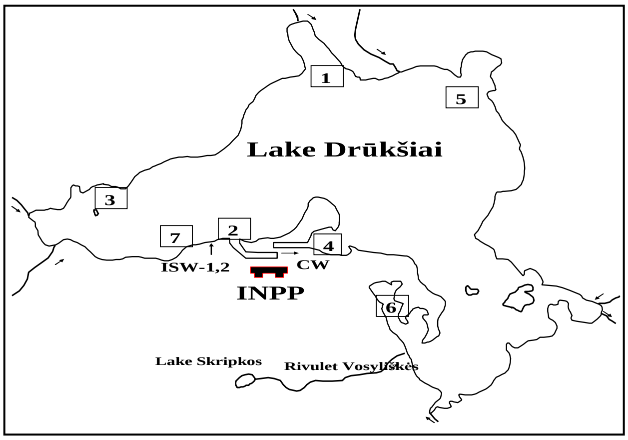

Fig 1. Scheme of the monitoring stations (1-7) of Lake Drūkšiai and discharge channels of the Ignalina NPP: ISW-1,2 – channel of industrial-storm water and process water discharge; CW – cooling water channel

Based on inhibition of root growth of *L. sativum* of 100–60 %, 61–40 %, 41–20 % and lower than 19 %, the toxic impact was classified as very strong, strong, moderate and slight, respectively. The tested sample was non-toxic if the inhibition of growth did not statistically differ from the control. A slight genotoxic effect on the *Tradescantia* clone 02 stamen hair (SH) system is observed when the number of somatic mutations does not exceed 1%, and non-viable SH are not observed. The moderate effect is observed when the number of somatic mutations is between 1–4 % and non-viable SH did not exceed 40 %. Strong genotoxic effect is characterized by the number of somatic mutations exceeding 4 %, and viability of SH cells is less than 40 % (Sparrow *et al.* 1972; Marčiulionienė *et al.* 2004).

The accumulation of ^{137}Cs, ^{90}Sr, ^{144}Ce, ^{106}Ru, ^{65}Zn and ^{59}Fe in the macroalgae *Nitellopsis obtusa* and in the higher aquatic plant *Elodea canadensis* was studied and the influence of thermal factor (31^{o}C) on the accumulation of these radionuclides in the aquatic plants was determined under laboratory conditions. The standard radioecological methods were used performing the above mentioned investigations (Foulquier *et al*. 2001; Marčiulionienė *et al*. 2001; Marčiulionienė 2003). To evaluate the levels of the radionuclide accumulation in plants, the concentration factor (CF) was used. It was calculated using the ratio $CF=C_1/C_2$, where C_1 is the radionuclide activity concentration in plant or cells compartment, and C_2 is the radionuclide activity concentration in water.

Statistical analysis was performed using Statgraphics plus for Windows Version 2.1. Statistical Graphics Corp. (USA).

3. Results and discussion

Long-term radioecological investigations of Lake Drūkšiai showed that the highest values of ^{137}Cs, ^{60}Co and ^{54}Mn activity concentration in hydrophytes and bottom sediments (43 and 292 Bq/kg for ^{137}Cs, 73 and 70 Bq/kg for ^{60}Co, as well as 59 and 52 Bq/kg for ^{54}Mn, respectively) was estimated in 1988–1993 when both Units of Ignalina NPP were operating (Fig 2). Activity concentration of tested radionuclides in hydrophytes and bottom sediments of the Lake decreased since 1996 and varied from 17 to 4 and from 131 to 105 Bq/kg for ^{137}Cs, from 20 to 7 and from 13 to 3 Bq/kg for ^{60}Co and from 26 to 2 and from 2 to <mdl (minmal detectable level) Bq/kg for ^{54}Mn, respectively. The literature (Adlienė, Adlytė, 2005) indicated that the values of activity concentration in aquatic plants of Lake Drūkšiai varied from 2.5 to 14.1 Bq/kg for ^{137}Cs, from 0.46 to 7.5 Bq/kg for ^{60}Co, and from 0.87 to 3.74 Bq/kg for ^{54}Mn in 2001–2004.

The values of ^{137}Cs activity concentration in bottom sediments of Lake Drūkšiai were higher (up to 10 times) than that in hydrophytes. However, activity concentration of ^{60}Co and ^{54}Mn in bottom sediments were lower (from 2 to 7 times and from 2 to 13 times, respectively) than that in hydrophytes or were the same or differed little between. Investigations performed in 2007–2009 showed, that after the decommissioning of the Unit 1, the activity concentration of ^{60}Co and ^{54}Mn in bottom sediments of Lake Drūkšiai decreased (from 5 to 2 Bq/kg) in the most cases. Though the values of ^{137}Cs activity concentration in bottom sediments of lake diminished, they were markedly higher than that of the other tested radionuclides. Consequently, the bottom sediments of the Lake remain ^{137}Cs deposit medium.

Long-term (1992–2000 and 2007–2009) ecotoxicological investigations showed that toxic impact of water and bottom sediments of Lake Drūkšiai varied from weak or non-toxic to strong for *Lepidium sativum*, and for *Tradescantia* it was medium or strong (Fig 3, 4). The strongest toxic effect of bottom sediments to *Lepidium sativum* was observed in 2008 (the roots did not grow) and in 2009 (the roots growth was only 14.8% in compare with control). The strongest radioactive and chemical pollution in Lake Drūkšiai was determined during 1988–1993; as well as the greatest genetic changes caused by lake's water in *Tradescantia* were observed in 1993 (Fig 4). Such changes in biological tests could be one of the reasons that caused changes of the Lake ecosystems resulting in degradation of these communities due to extinction of species in them (Stankevičiūtė, 2007). Degradation of plant vegetation in cooling water impact area could be also related with the impact of rather high temperature of CW discharged into the lake.

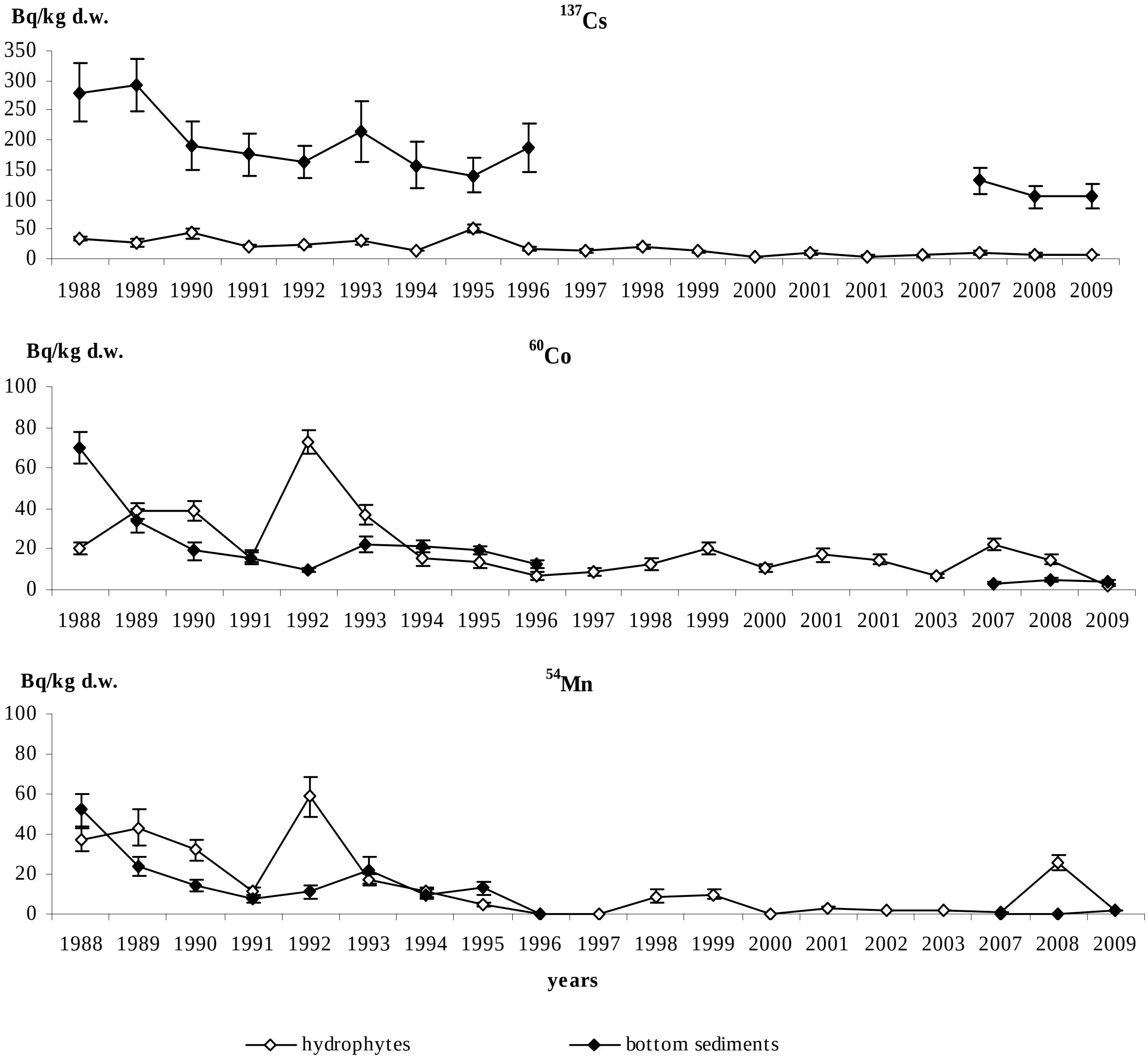

Fig 2. Activity concentration (average values) of radionuclides in hidrophytes and bottom sediments from Lake Drūkšiai

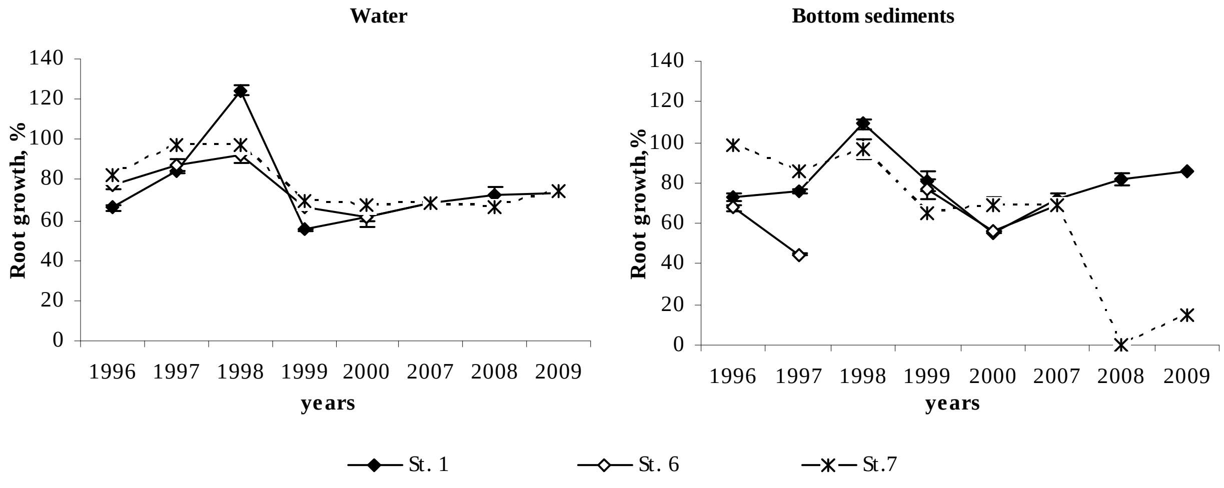

Fig 3. Toxic effect of water and bottom sediments from monitoring stations (1, 6, 7) Lake Drūkšiai on *Lepidium sativum* root growth

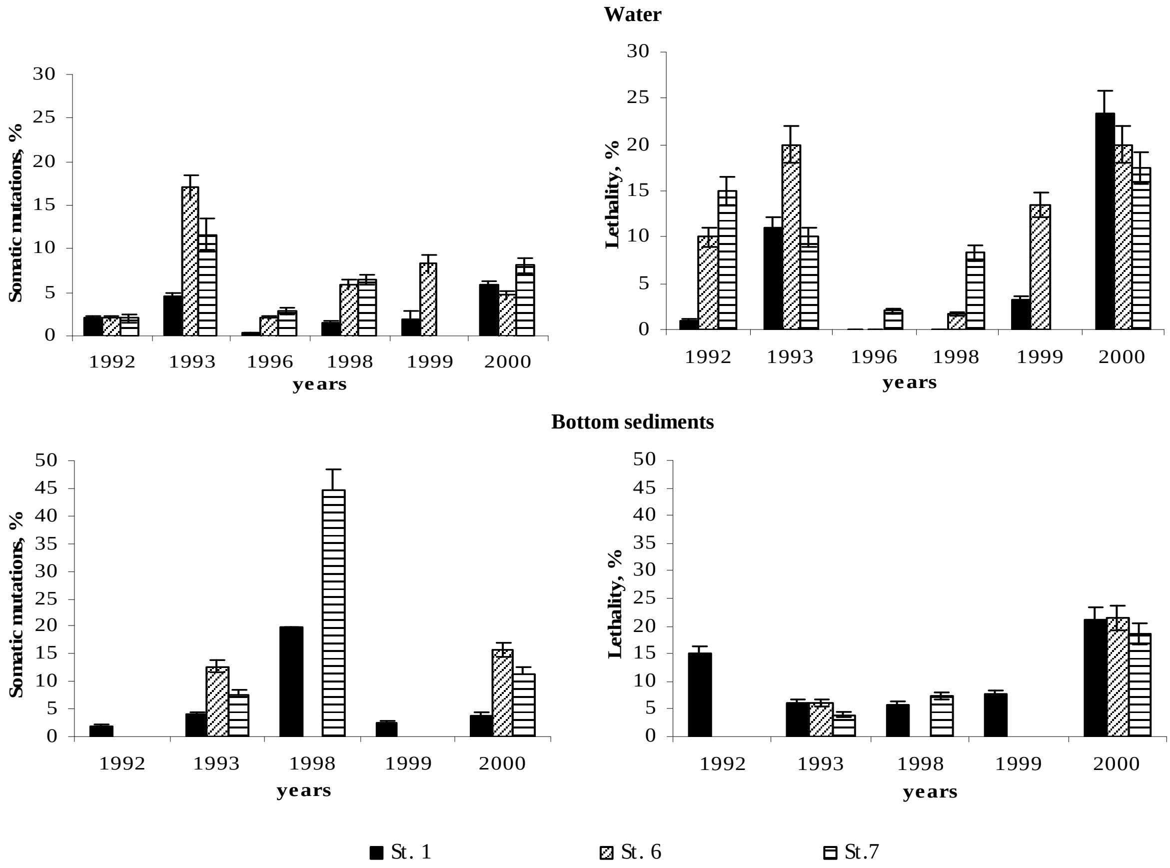

Fig 4. Genotoxic effects of water and bottom sediments from monitoring stations (1, 6, 7) Lake Drūkšiai in accordance with number of somatic mutations and letality of *Tradescantia* clone 02

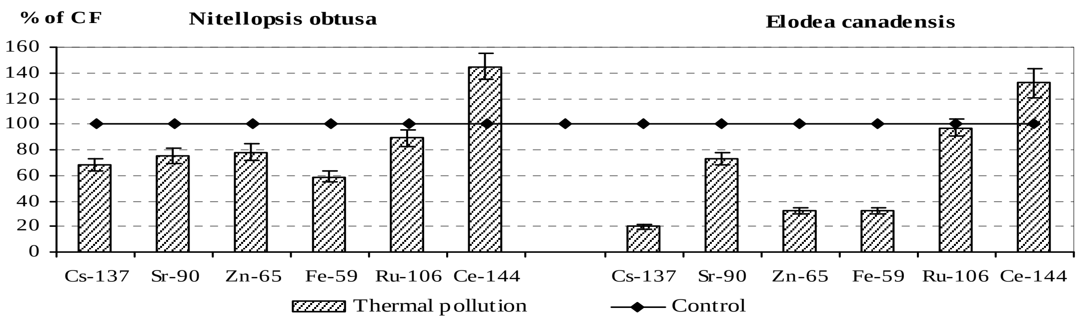

Fig 5. Impact of thermal pollution (31°C) on radionuclide accumulation (% of CF in the control at 22°C) in algae *Nitellopsis obtusa* and higher plant *Elodea canadensis*

It is known that stimulation of the growth of aquatic plants under high temperature of water is deviated from the normal functioning of plants (Marčiulionienė 2003). Hence, we may conclude that after the rapid development of the all species of plant of Lake Drūkšiai (1986–1989), the suppression of species, more sensitive to high temperature, had occurred. Temperature of water is one of the main factors which influence the physiological state of plant and it is strongly related with the sensitivity of plants to chemical and radioactive matters (Marčiulionienė 2003). Accumulation of radionuclides in the *Nitellopsis obtusa* and *Elodea canadensis* under laboratory conditions showed that the increase in water temperature from 22 to 31°C influenced the accumulation levels of different radionuclides in the tested plant species differently (Fig 5). While accumulation levels of ^{137}Cs, ^{90}Sr, ^{65}Zn and ^{59}Fe in the tested plants decreased from 1.5 to 4 times, accumulation level of ^{144}Ce increased by 2 times, and accumulation level of ^{106}Ru – changed slightly (Fig 5). It was found that impact of thermal and chemical pollution on accumulation of ^{137}Cs (chemical analogue of K) taking part in the metabolic processes in the aquatic plants may depend more on changes of the functional status of plant. Accumulation of microelement ^{60}Co and ^{54}Mn participating in metabolic processes of the aquatic plants under thermal impact may depend on both the functional status of the plant and changes of physical-chemical properties of these radionuclides (Marčiulionienė *et al*. 1992).

Studies of the impact of thermal factor on the aquatic plants showed that the speed of protoplasm movement and cell growth in length of *Nitellopsis obtusa* increased markedly with the increasing of water temperature from 19 to 30 °C. But already on the 14-th day the death of 50 % of plant cells was observed (Marčiulionienė *et al*. 1992). This shows that thermal factor can reduce plant vitality and cause it death. The thermal factor increases Pb accumulation in plants and its access to the inner cells compartments and it enhances the toxicity of this metal to the aquatic plants. According to the obtained data we can state that thermal factor, affecting the physiological status of the aquatic plant, may change not only accumulation levels of radionuclides in plants and their access to the inner cells compartments, but it can also influence the toxic and genotoxic impact of radionuclides on plants (Marčiulionienė *et al*. 2011).

It is known that the amount of oxygen in water can decrease with the increasing of water temperature. Due to the lack of oxygen the physiological status of the aquatic plant worsens and it depends on the sensitivity of tested plant to thermal factor. In addition, the thermal factor can increase mobility of metals, which are easily hydrolyzing, and salt of their radionuclides in water, and the adsorptive diffusive processes. This fact plays an important role in the accumulation of metals and their radionuclides in the aquatic plants and in their cells.

4. Conclusions

1. Summarizing the results obtained during the period of 1988–2009 it may be stated that radioecological situation of Lake Drūkšiai after 1996 is quite good. The ecotoxicological state of the lake changed little during this period, however, in some cases the tendencies of the toxicity increase in water and bottom sediments were observed. It could be mainly caused by rather high thermal pollution and constant discharges from Ignalina NPP during it operating period. The other important factor is toxic substances accumulated in the bottom sediment of lake during that period. Investigations showed that toxicity and genotoxicity of water and bottom sediments of Lake Drūkšiai was caused more not by radioactive pollution, but by the total impact thermal, chemical and radioactive pollution. In addition, thermal and chemical pollution could influence the accumulation levels of radionuclides in hydrophytes of Lake Drūkšiai and their distribution between components of the lake ecosystem.
2. It was found that the impact of thermal pollution on physiological status of the aquatic plants may change not only accumulation levels of tested technogenic radionuclides in plants and their access to the inner cells compartments, but it can also affected toxic impact of radioactive pollution on plants.

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