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ORIGINAL ARTICLE

Biological control of the invasive snail species *Melanoides tuberculata* and *Tarebia granifera* in Zaporizka Nuclear Power Plant cooling pond

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Abundance and biomass of the invasive thiarid snails such as *Melanoides tuberculata* (Müller, 1774) and *Tarebia granifera* (Lamarck, 1822) were studied in conditions of the cooling pond of Zaporizka NPP (Nuclear Power Plant) in autumn, 2017. The total biomass of *M. tuberculata* and *T. granifera* averaged 12.39 g/m^2 in the cooling pond and 177.69 g/m^2 in the upstream channel. In order to resolve the problem of snail foulings, an attempt was undertaken by means of introduction of such snail-feeding predatory species as black carp, *Mylopharyngodon piceus* (Richardson, 1846) and *Anentome helena* (von dem Busch, 1847). As shown by the aquarium experiment, the level of thiarids consumption by the hostile snail declines in the presence of tilapia *Oreochromis mossambicus* (Peters, 1852) living in Zaporizka NPP' cooling pond, as its fecal pellets are the additional food for *A. helena*. Taking into account the literature data, results of the model experiment and especial conditions of constructions and water bodies within the thermal structure of NPP, the introduction of the *A. helena* snail was proposed for biological control of the invasive species (*M. tuberculata* and *T. granifera*) primarily inside of pipes, and the fish predatory species was preferably provided for the cooling pond and upstream channel of Zaporizka Nuclear Power Plant.

Keywords: biological control; Zaporizka Nuclear Power Plant; introduction; *Melanoides tuberculate; Tarebia granifera; Anentome helena*

Introduction

The problem of biological fouling is of great importance for nuclear thermal power plants maintenance. Fouling caused by the hydrobionts of plant or animal origin reduces effectiveness of NPP facilities and may lead to the complete blockage of water pipelines. In conditions of nuclear power plants, high water temperature creates favorable conditions for the intensive development of specific thermophilic species as repeatedly noted in the literature (Protasov et al., 1991; Sakaguchi, 2003; Sylayeva et al., 2012). During 2000–2008, biological fouling of different origin caused up to 40 emergency shutdowns of NPP units due to the blockage of the cooling water supply around the world. Blue-green algae and *Dreissena* mussels are the common hydrobionts causing biotic barriers in freshwater hydrotechnical systems.

Abiotic factors affect the dynamics of aquatic organisms (Bondarev, Zhukov, 2017). The interspecies interactions also play an important role (Zhukov, Gubanova, 2015 a,b). The reports concerning the spread of tropical invasive Thiaridae snails such as *Melanoides tuberculata* (Müller, 1774) and *Tarebia granifera* (Lamarck, 1822) in the NPP cooling ponds of the Ukraine appeared lately (Novoselova et al., 2014; Orlova, 2010; Son, 2009). The *M. tuberculata* and *T. granifera* species are tropical freshwater Thiaridae gastropods, native to the Eastern Africa and the Middle East. These mollusks had spread extensively throughout the tropics (Laos, Vietnam, Hong Kong, Brazil, etc.) (Pointier, 1999). Parasitic population of aquatic organisms are sensitive to environmental conditions (Sokolov, Zhukov, 2014, 2016, 2017). The *M. tuberculata* and *T. granifera* snails threaten the health quality of various water bodies (Souto et al., 2011). It has been demonstrated that they can rapidly colonize many types of habitat (especially man-made substrates) where the snails can reach very high densities due to the parthenogenesis reproduction capability (Silva et al., 2014). These snails are considered harmful as they could be associated with exotic trematodes which affect native fish and birds being the intermediate hosts for human intestinal trematodes (Giovanelli et al., 2002). On the other hand, these gastropods are widely used in aquariums as they are helpful in loosening and oxygenation of the aquarium ground.

For the first time, the *M. tuberculata* species was registered in the cooling pond of the South Ukrainian NPP in 1997 (Grigorovich et al., 2002). In November 2005, its biomass varied from 6 to 35 g/m^2 there. Since then, this snail has reproduced in a huge amount and has become the dominant species, reaching 99% of the total number and biomass of zoobenthos in some parts of the cooling pond (Slepnev et al., 2013). In 2015, the *M. tuberculata* species was registered in the cooling pond of Zaporizka

Nuclear Power Plant (Klimchuk, 2015). In 2016, foulings of invasive snails began to create clogging in the pipes and on fine filters of tower pump stations of Zaporizka NPP, which indicates the significant increase of the snail abundance since 2015.
The ways for control the foulings induced by biological agents in water bodies or hydraulic systems of this NPP are limited by the prohibition of physical and chemical agents use. Therefore, the biological method for controlling foulings is the priority in solving the problem of snail overgrowing. Despite the numerous evidences of the Thiaridae species growth in some NPPs, there are no recommendations for biological control of *M. tuberculata* or *T. granifera* intended for NPP facilities in Ukraine. Given the different constructions and water bodies within the thermal structure of NPP, it is advisable to apply the complex integrated approach using a multilevel system of these species management. The black carp (*Mylopharyngodon piceus*) is a well-known predator of freshwater snails and this fish species has been used successfully for biological control of *M. tuberculata* and *T. granifera* in various parts of the world (Hung, Duc et al., 2013; Ben-Ami et al., 2001). Meanwhile, black carp can be effective only in conditions of open water bodies whereas invasive thiarids inside of pipes or on cooling towers of NPP will be inaccessible for fish. Thus, the method of biological control needs small biological objects that can feed on invasive thiarids.
There are numerous evidences of the effectiveness or ineffectiveness of biocontrol of intensively reproducing detritophagous mollusks with the help of predatory mollusks in conditions of open water-bodies (Davis et al., 1964; Pointier et al., 1989; Nguma et al., 1982; and Nishida et al., 1975). Gastropods of the *Pomacea canaliculata* species used for biocontrol of some snail host for trematodes did not consume the *M. tuberculata* adults that might be explained by features of their shell hardness and structure (Kwong et al., 2009). Another species that can feed on snails such as *M. tuberculata* and *T. granifera* is *Anentome helena* (von dem Busch, 1847), the predatory snail. The *Anentome helena* species is sold in the aquarium trade as a biological agent intended for controlling the aquarium overgrowing by other snails including *M. tuberculata* (Bogan et al., 2013). Effective use of *A. helena* is reported from Malaysia and Indonesia, Thailand, and Laos (Schiffbauer, 2009). Therefore, it could be beneficial in conditions of warm water-bodies of the NPP system.
Taking into account the above mentioned, the purpose of this paper was to investigate the species composition and quantitative parameters of the zoobenthos in the cooling pond, upstream channel and water pipes of Zaporizka NPP, as well as, on this basis, to propose the biological measures for control of the invasive snails which create foulnesses.

Materials and Methods

In September–October 2017, distribution of zoobenthos has been studied by sampling at 6 sites in profundal and littoral zones of the cooling pond and in littoral zone along the upstream channel (fig. 1).

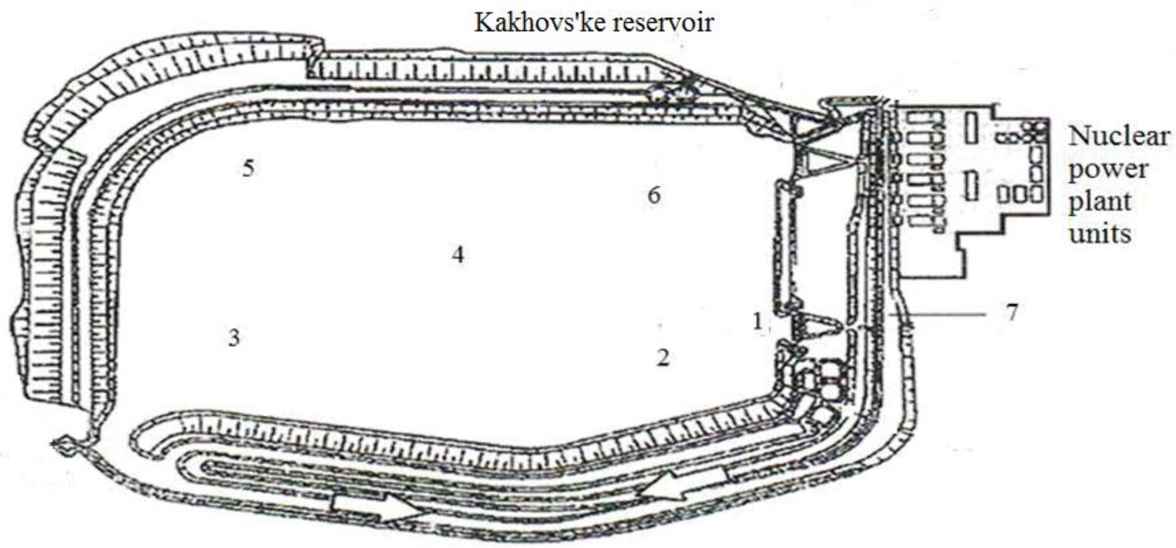

Figure 1. The sites of zoobenthos sampling in the cooling pond and in the upstream channel (47°30'44" N, 34°35'09" E): 1 – near the discharge of water from power units into the cooling pond, 2 – southern section, 3 – western section, 4 – central section, 5 – northern section, 6 – eastern section, 7 – upstream channel. The arrows show the direction of water in channels

In profundal and littoral zone of the cooling pond Birge-Ekman dredge was used to take samples of zoobenthos at the triple replication accordingly to the recommendations (Methods, 2006). For the identification of associated species (chironomids, oligochaetes, crustaceans, etc.) in addition to thiarids, the material sampled by Birge-Ekman dredge was washed through the sieve (300 μm mesh) with following fixation in 4% solution of formaldehyde. Therewith, the manual solid net with larger 600 μm mesh suitable for introducing into the sand was used to collect only thiarids in the littoral zone of both cooling pond and upstream channel from the surface restricted by the frame with 20 x 20 sq. cm area because thiarids often were found to be buried into the sand. The mesh size of 600 μm prevents the loss of thiarids, but the finer mesh sieve is quickly clogged with sand and large volume of sample is not placed in the container then. In addition, fouling samples were stripped off from the solid man-made substrates with the use of scraper. Then sampled material was fixated in 4% solution of formaldehyde. Weighting of mollusks was performed with electronic weigher.
During five weeks (between October, 8 and November, 13) in the laboratory of the General Biology and Water Bioresources Department, the model aquarium experiments were carried out to find out the effectiveness of *A. helena* as an agent controlling

M. tuberculata and *T. granifera.* The aquarium settings were modeled in accordance with real conditions of the cooling pond of Zaporizka NPP. The native molluscs, water, bottom sediments, sawyers and concrete structures were used for maximum real simulation of the cooling pond environment.

For the experiment, 10 individuals of *A. helena,* 20 individuals of *M. tuberculata* and 80 individuals of *T. granifera* were used because number ratio of *M. tuberculata* to *T. granifera* was close to 1:4 in the cooling pond and in pipes. The first aquarium contained only molluscs (No. 1) whereas another aquarium (No. 2) contained these mollusks together with tilapia (*O. mossambicus*). At the end of each week, molluscs were recalculated in both aquariums, and dead mollusks were removed. Then new Thiaridae snails were added to the aquariums in such a quantity that to complete the numbers of survived molluscs up to the initial ones for each species, therefore, at the beginning of each week, the number of *M. tuberculata* was equal to 20 individuals and that of *T. granifera* was equal to 80 individuals. The reference point allowing the comparison of results was at the beginning of the week that's why amount of new Thiaridae snails which were added to the aquariums were equal to those being consumed by *A. helena* for the previous week, so at the beginning of the week the initial conditions of the experiment were restored.

Results

In September and October, representatives of the *M. tuberculata* and *T. granifera* species were found in profundal zone and littoral zone only within the southern section. Spire of *M. tuberculata* shell was five times greater than the aperture height with moderately large body whorl (fig. 2). Aperture faces to the right. Shell was sculptured with vertical ribs and spiral striations and had dark dots irregularly distributed on shell surface. Ribs were more raised on upper whorls. Height of body whorl of *T. granifera* was more than half of the shell and sculptured with distinct spiral rows of nodules.

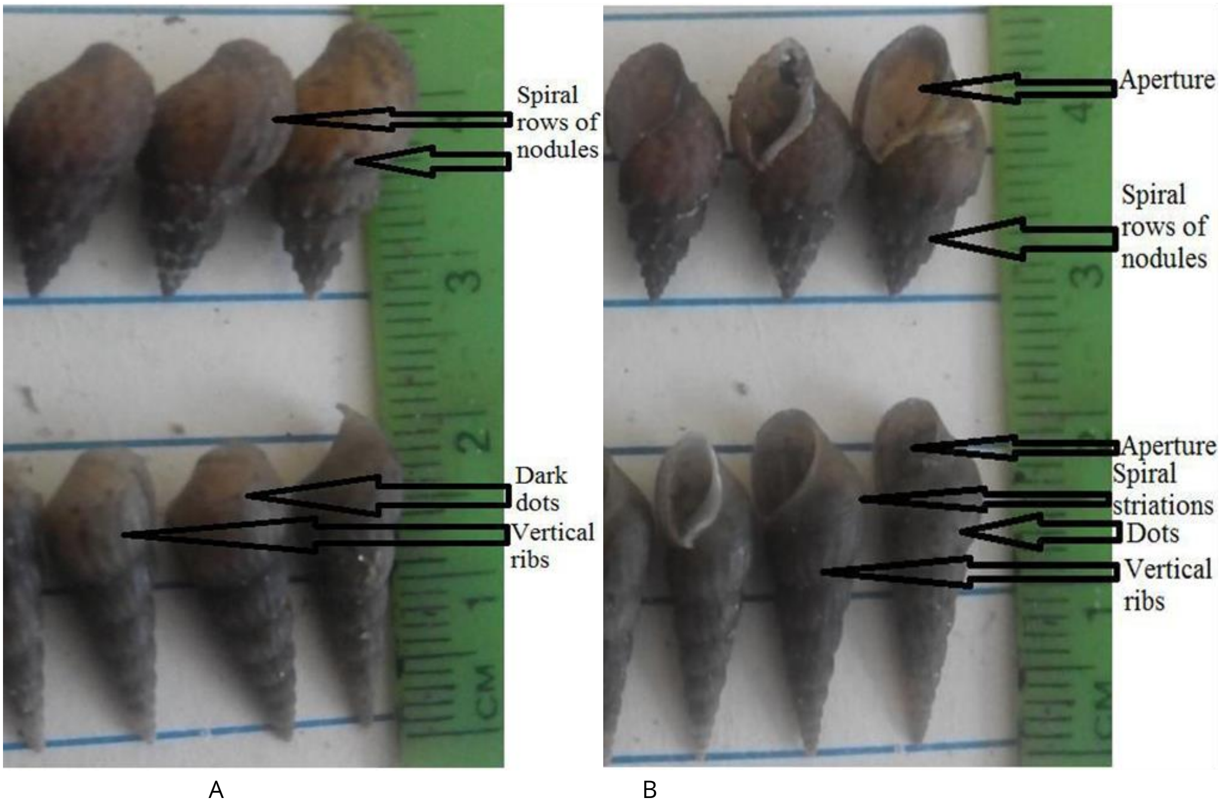

Figure 2. Dorsal view (A) and ventral view (B) of the adult snails *of Tarebia granifera* (Lamarck, 1822) (the upper row) and *Melanoides tuberculata* (Müller, 1774) species (the lower row).

Under the unequal distribution throughout the cooling pond, the average abundance of *M. tuberculata* was 20 ind./m^2, and biomass – 3.12 g/m^2, while the abundance of *T. granifera* equaled to 66.7 ind./m^2, and biomass – 9.27 g/m^2. Thus, the ratio of *T. granifera* to *M. tuberculata* was 3.3**:**1. In foulnesses of littoral zone near discharge of water from power units into the cooling pond, the abundance of *M. tuberculata* increased up to 60 ind/m^2 and biomass – to 7.36 g/m^2, while the abundance of *T. granifera* increased up to 300 ind./m^2 and biomass – to 47.8 g/m^2. Thus, within the foulnesses, the abundance of *T. granifera* was 5 times greater than the abundance of *M. tuberculata.*

In the upstream channel, representatives of the *M. tuberculata* and *T. granifera* species were found only in silted sand of shallow littoral zone (≤ 2 m depth) where the abundance of *M. tuberculata* varied from 40 to 240 ind./м^2 averaging 141.2 ± 52.9 ind./м^2, while the abundance of *T. granifera* varied from 320 to 1480 ind./м^2 averaging 682.5 ± 313.6 ind./м^2. Thus, the total abundance of thiarids averaged 823 ± 356 ind./m^2. Abundance of both Thiaridae species was minimal in the open littoral zone and rose in the cane beds. Large numbers of molluscs were found to be attached to underwater parts of cane. No living snails were found at a greater depth of the channel where crushed stone and gravel were the only bottom substrate.

In the conditions of pipes and cooling towers, the number of *M. tuberculata* varied from 200 to 1140 ind./м^2 averaging 639 ± 341 ind./м^2, while abundance of *T. granifera* varied from 900 to 5200 ind./м^2 averaging 2569 ± 1354 ind./м^2. Total number of thiarids in pipes varied from 1040 to 6340 ind./m^2, in average 3132± 1651 ind./m^2. Such a great abundance of the snails, probably, was due to the high temperature inside of pipes and cooling towers throughout a year. The mean length of *M. tuberculata* was 14.33 ± 6.12 mm varying from 2 to 21 mm. The mean length of *T. granifera* was 8.27 ± 2.83 mm varying from 2 mm to 17 mm. For *M. tuberculata,* the lengths of the snails were divided into five size classes, as follows: 1 – 5 mm, 6 – 9 mm, 10 – 13 mm, 14 – 17 mm,18 – 21 mm, among which the 10 – 13 mm size class was the most frequent. For *T. granifera* the lengths of the snails were divided into the following four size classes: 1 – 5 mm, 6 – 9 mm, 10 – 13 mm, 14 – 17 mm, and the 6 – 9 mm size class was the most frequent.

During the laboratory experiment, the first aquarium contained only molluscs (No. 1) whereas another aquarium (No. 2) contained these mollusks together with tilapia (*O. mossambicus*). Accordingly to the results, in the aquarium No. 1 where only snails were present, one *A. helena* consumed from 2.8 to 6.3 Thiaridae individuals averaging 5.02 ± 1.58 mollusks per week (tab. 1).

Table 1. The rate of consumption (number of individuals) of the *Melanoides tuberculata* (Müller, 1774) and *Tarebia granifera* (Lamarck, 1822) snails by 10 individuals of *Anentome helena* (von dem Busch, 1847) during the laboratory experiment.

	week 1	week 2	week 3	week 4	week 5
Experimental conditions: Thiaridae species + *Anentome helena*					
Melanoides tuberculata	6	8	13	13	1
Tarebia granifera	22	31	47	50	51
Experimental conditions: Thiaridae species + *Anentome helena* + *Oreochromis mossambicus*					
Melanoides tuberculata	3	3	7	6	7
Tarebia granifera	8	15	20	18	17

The rate of the thiarids consumption was increasing from the first to the third weeks and then it continued at the constant level. In the first turn, the larger individuals of *M. tuberculata* were consumed. The thiarids accumulated mostly on a concrete slab, they also buried into the sand and often concentrated near the water heater. The *A. helena* snails attacked and consumed thiarids mostly in large groups (fig. 3). The highest percentage of Thiaridae molluscs consumed by *A. helena* was registered during the fourth week of the experiment. The gradual increase in the number of thiarids consumed by *A. helena* is explained by its progressive adaptation to the new conditions in the aquarium. This conclusion was done because it is well-known that under adaptation of snails the volume of food consumed by them increases.

Figure 3. The group of *Anentome helena* (von dem Busch, 1847) individuals is consuming the *Melanoides tuberculata* (Müller, 1774) and *Tarebia granifera* (Lamarck, 1822) snails.

The molecular sequencing method used in the study (Strong et al., 2017) showed that the *Anentome helena* name comprises a complex of at least four species. Based on external anatomy of these species given in the paper mentioned, the species used in our experiment corresponds to the *Anentome* sp. A species (see fig. 3).

In conditions of high water temperature in the cooling pond and channels of Zaporizka NPP, tilapia became the very abundant and dominant fish species. Besides, its fecal pellets are the additional food for the "flexible predator" *A. helena* (Behrendt, 2009). The predominant native food of this snail consists of decaying animals, living worms and snails (Hung, Stauffer et al., 2013). That is why it is important to investigate the thiarids consumption by *A. helena* in the presence of tilapia, given that the additional source of food may be the factor limiting the consumption of living snails, even to the extent that predation ability renders no effect on population densities of the extremely fecund and rapidly reproducing Thiaridae species. During the laboratory experiment in the aquarium No. 2, where all three snail species and *Oreochromis mossambicus* were present, the rate of the thiarids consumption by *A. helena* was significantly lower compared to the aquarium No. 1, and varied from 1.1 to 2.7 averaging

2.08 ± 0.64 ind. of Thiaridae snails per week. Unlike the experimental variant without tilapia, the maximum of consumption rate was observed at the third week. Probably, the process was inhibited by accumulation of tilapia excrements that had led to the increasing role of available additional source of food.

Discussion

There is no evidence concerning vectors of the Thiaridae thermophilic species introduction into the water bodies of Ukraine, but aquarium releases can be the most probable vector. These mollusks get into the water bodies while pouring out the water from the aquariums, and they survive only in the conditions of thermally enriched waters. In the conditions of Zaporizka NPP, the ways for controlling the foulnesses induced by biological agents in hydraulic systems are limited by the prohibition of physical and chemical agent application. Mechanical methods for cleaning water pipes from overgrowing are laborious and ineffective since they don't eliminate the cause, but only the consequences. Therefore, the method of biological control of fouling is the priority in solving the problem of snail overgrowing. Despite the numerous evidences of the appearance of the *M. tuberculata* or *T. granifera* snails in some NPPs, there are no recommendations for biological control of these Thiaridae thermophilic species for ponds or man-made facilities of NPPs in Ukraine. In order to achieve the effective fouling management by a biological method in varying water bodies or units of NPP, a complex integrated approach using different biological agents is advisable to be applied. Besides, it should be appropriate, convenient, and successful in reduction of the total snail abundance. Taking all this into account, we have developed the two-level technology of the Thiaridae species biological control using the molluscivorous fish and snail species.

While being a well-known predator of freshwater snails, the black carp (*Mylopharyngodon piceus*) was used successfully for biological control of *M. tuberculata* and *T. granifera* in various parts of the world ((Hung, Duc et al., 2013; Ben-Ami et al., 2001). Enameloid, the outermost layer of black carp teeth, possesses similar elastic modulus and hardness in comparison to those of the pond snail shells (He et al., 2013). In average, black carp consumes 19 g of *M. tuberculata* per day (Ben-Ami et al., 2001). It was also found that black carp of smaller sizes preferentially fed on *M. tuberculata,* and proportion of consumed *M. tuberculata* individuals declined while increasing their shell height (Hung, 2013), as the adult thiarids were well protected by a hard shell and an operculum (Kwong et al., 2009).

Controlling of the snails should be an integrated strategy including broad variety of measures depending on specific habitat of the species under investigation. In addition to the cooling pond, there is a complex system of hydrotechnical facilities (upstream and downstream channels, cooling towers, thrash screens, spray cooling tower, pumping facilities, pipes, etc.) within the bounds of Zaporizka NPP. Meanwhile, black carp can be effective only in conditions of open water bodies whereas invasive thiarids inside of pipes or on cooling towers of NPP will be inaccessible for fish. Thus, the method of biological control needs small biological objects that can feed on invasive thiarids. Such a molluscivorous species that can eliminate *M. tuberculata* and *T. granifera* snails is *Anentome helena* (von dem Busch, 1847), the predatory gastropods. In literature, *A. helena* is mentioned as a successful biological agent for control of other harmful snails in conditions of aquariums (Schiffbauer, 2009). Therefore, it could be beneficial in conditions of warm basins of the NPP system.

Numerous reports can evidence concerning the effective or non-effective biocontrol of intensively reproducing detritophagous mollusks with the help of predatory mollusks in conditions of open water-bodies (Davis et al., 1964; Pointier et al., 1989; Nguma et al., 1982; and Nishida et al., 1975). Generally, the complexity of predator/prey interactions is shown in the literature resources. They demonstrate that it is extremely difficult to prove that predation limits prey populations and often it may not (Sih et al., 1998). Therefore, the theory underpinning this aspect of biological control is complex (Murdoch et al., 1996). In few cases of putative biological control using snails, the gastropod predatory agent indeed has been demonstrated to have the potency to control the pest populations.

Despite the reports concerning the influence on hydrobionts of host aquatic ecosystems, there are several factors causing the environmental safety of the *A. helena* introduction into the cooling pond and the circulating system of Zaporizka NPP, as follows:

1. As a predator species, *A. helena* could hypothetically destroy the ecosystem only in the conditions of tropical water-bodies, but invasion of *A. helena* into the Kakhovs'ke reservoir from the cooling pond would be restricted by the temperature below 20°C in the reservoir during 9 months. The temperature optimum of *A. helena* is within the diapason from 18 to 27°C. As soon as the temperature drops below 18°C, *A. helena* starts starvation followed by the death of these molluscs (Bogan et al., 2013).
2. It should be emphasized that the case of NPP cooling pond or channels is unique unlike other open reservoirs. *A. helena* could hypothetically transform the ecosystems of these water-bodies. But the only purpose of these basins is to cool the water coming from the power units. Therefore, the priority task is to minimize the number of mollusks causing the foulness whereas there is neither of the cooling pond, nor the aim of its ecosystem conservation. The total number of snail individuals is the key guiding factor for the proper NPP functioning in contrast to native water ecosystems. Moreover, the cooling pond is prohibited to be used for harvesting fish or other water resources.
3. One of the important factors is that the introduction of *A. helena* is proposed for consumption of thiarids primarily inside of pipes, where there are no food sources for *A. helena* except thiarids. Besides, there is no biological agent apart from *A. helena* that could reduce the number of thiarids inside of pipes. It is necessary to comply with the technology of thiarids introduction in batches into the pipes while conducting the repair operations connected with absence of flow there, with the aim to prevent the washing-off of added mollusks from the pipes.
4. Being the detritophagous species, the thiarids reproduce unrestrictedly in the absence of predators. By contrast, being the predatory species, *A. helena* will consume primarily thiarids. Reproduction of *A. helena* depends on thiarids numbers and will be restricted due to the predator-prey negative feedback loop. Increase in predators leads to decrease inpreys. Alternatively, decrease in predators leads to increase in preys. That's why population of *A. helena* will not reach a huge abundance. In the

absence of the predator pressure, i.e. in modern conditions of Zaporizka NPP water bodies, the population dynamics of the Thiaridae snails number (*Nt*) is described by the Malthus equation:

$$Nt = N_0 * e^r \quad (1)$$

where N_0 – the initial number of thiarids, *e* – the base of natural logarithm, *r* – the exponent reflecting the rate of thiarids reproduction. The above equation explains the sharp increase of thiarids abundance in the absence of predatory pressure: without this hostile factor, abundance of the thiarids population increases exponentially. The greatest negative consequence of the unlimited thiarids reproduction appears in the pipes and leads to their clogging. Under introduction of the predator snail such as *A. helena* into the pipes in the absence of any additional feed, the dynamics of the numbers of one predator per one victim should be described with the Lotka-Volterra equation:

$$\frac{dN}{dt} = r * N - a * C * N \quad (2)$$

where *N* – the number of thiarids; *a* – the efficiency of thiarids search by *A. helena*; *C* – the number of *A. helena*; *r* – the exponent reflecting the rate of thiarids reproduction.

Accordingly to the equation above, at the start of introduction, increasing numbers of both thiarids and *A. helena* should enhance the probability of their meetings. But during the next year the total number of individuals of *A. helena, M. tuberculata* and *T. granifera* species turns out to be much smaller than the number of only thiarids in the absence of the predatory snail which reflects the reduction of fouling inside of pipes. Thus, this equation supports the efficiency of the proposed method of biological control of the invasive snail growth.

5. The suggested technology includes the multilevel biological control, since black carp will serve as an additional buffer in the ecosystem while consuming both thiarids and *A. helena* in open water-bodies (cooling pond and channels) of NPP. Thus, combined introduction of both the predatory snail and black carp will be the implementation of an integrated approach for achieving the biocontrol of harmful invasive species. The calculation of the snail introduction could be approximate here. For accurate calculation, it is necessary to develop a mathematical model that should take into account the dynamics of predator and prey abundances, the influence of black carp and tilapia, the consumption of black carp by cormorants, etc. The construction of such a model requires further research.

Accordingly to the technology mentioned, it is advisable to stock the cooling pond and the upstream channel with two-year-old individuals of black carp. This is explained by the greater survival of the two-year-old fish compared to the under yearlings due to the smaller rate of consumption them by cormorants.

Since the highest efficiency of the thiarids consumption by *A. helena* was observed in conditions of collective hunting, it is advisable to introduce *A. helena* to the southern section of the cooling pond in the amount of 5300 individuals in May. Also, it is recommended to introduce 30 individuals of *A. helena* every 50 meters along both banks of the upstream channel, with the total amount of 5400 individuals should be added finally. As a result, only the introduced individuals of the *A. helena* snail will have consumed 330.5 thousand thiarids in the cooling pond and 336.8 thousand thiarids in the upstream channel by the end of a year. This is due to the presence of additional food in the form of tilapia feces otherwise the rate of thiarids consumption would be even higher. Mechanism of biocontrol with the help of the predatory snail isn't immediate, but the compliance with technology based on this mechanism will be strategically required for some time until the *A. helena* species reproduces in sufficient quantities in the cooling pond and in channels. The life span of *A. helena* constitutes 4 years. The snail lays one egg, but due to the high spawning frequency, its abundance increases quite rapidly. Given the average rate of the predatory snail reproduction, the number of thiarids consumed by *A. helena* during the next season will increase to 11.56 mln. ind. (million individuals) in the cooling pond and 11.79 mln. ind. in the upstream channel.

The total length of the pipes, which are connected with each NPP unit, reaches 4.5 km and their average diameter is 0.5 m. Because of too high temperature (more than 35ºC) of water flowing from NPP units, the habitation conditions for these snails are suitable only for the section of pipes reaching the border of 0.5 km from the pipe valves situated near the cooling pond. Average abundance of living thiarids on the inner surface of the pipes was 3132 ± 1655 ind./m^2, and, thus, there are about 4.92×10^6 thiarids inside of the pipes connected with each NPP unit. Taking into account that in the absence of additional food one snail of *A. helena* consumes an average of 0.72 thiarids a day provided the maximum effectiveness of *A. helena* collective predation, it's advisable to introduce 10 individuals of predatory snails per day, during the conduction of repair operations, into the pipe holes of each NPP unit coming from the side of pipe valves near the cooling pond. Batch mode of *A. helena* introduction is important to avoid the pipes clogging by corpses of thiarids and alive snails of *A. helena*. The specified amount of *A. helena* would stabilize the abundance of thiarids in the pipes. Under the subsequent flushing of pipes, it is necessary to pay attention to alive snails of *A. helena*, returning them back to the pipes. Provided that all these measures are carried out, the meaningful result will be appeared soon, since only the introductive predatory snails will have consumed 0.48×10^6 thiarids in the pipes of each NPP unit during the current year and 0.96×10^6 (due to the *A. helena* reproduction) – during the next year. In the following, provided stable reproduction of *A. helena,* there will be the balancing feedback loops between predator and the total number of mollusks which would prevent to exceed several hundred thousand individuals per the pipe of each NPP unit.

It is necessary to take into account the Thiaridae snails remaining on cooling towers, water boards, pumping stations and other surfaces. However, since these surfaces are open, it is rational to clean them mechanically instead of *A. helena* introduction onto these surfaces.

Conclusions

Under unequal distribution throughout the cooling pond, the total average abundance of the Thiaridae snails (*M. tuberculata* and *T. granifera*) was 86.71 ± 23.43 ind./м^2, and biomass – 12.39 ± 5.86 g/м^2. The ratio in abundances of *T. granifera* to *M. tuberculata* was 3.3**:**1. The thiarids abundance was maximal in the pipes varying from 1040 to 6340 ind./м^2, in average 3132 ± 1655 ind./м^2. Under experimental conditions, the thiarids consumption by *A. helena* was the most effectively within the environment with a minimum concentration of organic matter that could be the additive food source for this predatory species. Taking all above into account, the two-level technology of the Thiaridae species biological control, which should be appropriate, convenient, and successful in reducing the total snail abundance, is advisable to be applied. The molluscivorous species such as the black carp (*Mylopharyngodon piceus*) and the gastropode *A. helena* are implied to be introduced in parallel, with stocking the cooling pond and the upstream channel with two-year-old individuals of black carp and with the total amount of 5300 – 5400 individuals of *A. helena* (as for the cooling pond, the southern section is preferable for this species) in May. It is also recommended to introduce 10 individuals of predatory snails per day into the pipe holes of each NPP unit coming from the side of pipe valves near the cooling pond during the conduction of repair operations.

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