ZOOPLANKTON FEATURES IN THE AQUATIC AREA INFLUENCED BY CERNAVODĂ NUCLEAR POWER PLANT

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Abstract: Thermo-electric power plants, including nuclear plants, affect aquatic organisms entrained through water cooling systems by reducing their motility or increasing mortality. The negative effect of Cernavodă Nuclear Power Plant on zooplankton motility was evaluated by using water samples collected from six points in the adjacent aquatic area in July 2010. We defined a non-motility index as the ratio between non-motile organisms and the total abundance of zooplankton species. This parameter has specific values depending on local environmental conditions. At the sampling points, not affected by the cooling system, the zooplankton non-motility index had a maximum value of 7.6%. Following the cooling system, in the hot effluent discharge water, the zooplankton non-motility index value was raised up to 29.3%. In the mixed zone of warm effluent with the Danube waters the zooplankton non-motility index showed higher values than in unaffected areas, but less than in the warm effluent, up to 16.4%.

Key words: Danube River, Nuclear Power Plant Cernavodă, zooplankton abundance, zooplankton non-motility index

1. INTRODUCTION

The environmental impact of the nuclear power plants is an issue all over the world. Moreover, the effects of the cooling systems on entrained organisms have been evaluated in numerous studies.

Romanian Nuclear Power Plant (NPP) situated near Cernavodă, with two reactors of 700 MW each, uses about 92 m^3/s water from the Danube River (H.G.1515, 2008) for its open cooling system. This study is based on the results of the research performed on zooplankton populations in the aquatic area influenced by Cernavodă NPP, in July 2010.

Zooplankton entrained through the cooling system is negatively affected by mechanical, hydrodynamic, thermal and chemical processes (Bamber and Seaby, 2004; Choi *et al.*, 2012; U.S. EPA, 2004). These effects can be highlighted by evaluating the non-motile individuals both at the input and output of the water cooling system.

Similarly to the mortality index (Marcy *et al.*, 1978; Davies and Jensen, 1975), the authors introduced the non-motility index term as the ratio between non-motile organisms and the total abundance (motile and non-motile).

From a biophysical point of view, zooplankton motility is the spontaneous and active movement capability based on energy consumption of these organisms. This term is equivalent to the free motions (swimming, jumping, random walking) determined by the biologic behaviour of each organism. If the movement abilities of one zooplankton individual are affected, then that organism is considered non-motile. The non-motile organisms include all dead individuals and individuals alive with altered movement functions, which cannot access food or avoid predators and, consequently, die by starvation or predation. The mass densities of the most zooplankton organisms have a slightly higher value than the density of the water and, due to this fact, all non-motile individuals have a sinking movement component in the water column. From a hydrodynamic point of view, non-motile zooplankton is an inert particle and its movement is ruled only by physical laws. The existence of downward movement of dead zooplankton organisms was pointed out in many studies, with the aim of determining the rate of mortality (Gladyshev *et al*., 2003; Kirillin *et al*., 2012).

2. METHODS

For this study, six water sampling points (S1÷S6) were chosen along the cooling pathway (Fig.1):

S1 – located on the Danube River, 500 m upstream the Anghel Saligny Bridge, in line with the second bridge pillar from the right side; it is considered a reference station because this ecosystem is not affected by thermal discharge from the NPP Cernavodă.

S2 – is a sampling site placed at the income water basin of NPP; here the water is coming from Danube via Danube – Black Sea Canal.

S3 – is a site situated on the effluent discharge canal of NPP, upstream the aeration waterfall; here the temperature of the water is expected to reach the maximum values.

S4 – is a site located downstream the waterfall of the NPP discharge canal and 100 m upstream the confluence between this canal and the Danube River.

S5 – is located on the Danube, 300 m upstream the confluence between the NPP discharge canal and 150 m away from the shore.

S6 – placed on the Danube River, in the thermal plume, 500 m downstream the confluence between the NPP discharge canal and the river.

On July 26, 2010, we acquired sampling data on zooplankton populations in these aquatic areas.

The samples were collected using a Schindler-Patalas plankton trap with a 65 μm mesh-size. In each sampling point, the water temperature was recorded, too.

Fig. 1. Location of sampling points in the study area (picture processed after Google Earth)

Table 1. ANOVA test for site samples

Fcritic = 3.5545	S1	S2	S3	S4	S5	S6
F	5.92E-03	3.18E-03	1.74E-02	6.55E-05	4.62E-03	9.63E-03
P (same)	0.9941	0.9968	0.9828	0.9999	0.9954	0.9904

Triplicate samples were taken for statistical evaluations, for each site S1÷S6, and tested by ANOVA. The values of F factor and P probability indicated that each set of three samples had the same average value, which were used in these papers (Table 1).

Based on the sinking movement component of non-motile zooplankton individuals mentioned above, a method was developed for separating motile from non-motile zooplankton floating in a water sample. Briefly, 0.5 liter of water, which contains motile and non-motile organisms, is placed in a Plexiglas cylinder, of 40 mm diameter and about 1000 mm length. At the bottom part of the tube, there is a rubber balloon. Due to sedimentation movement, the non-motile zooplankton will be settled in the lowest part of the balloon. After an appropriate period of time (about 2 hours) it is assumed that all the non-motilities settled in the balloon. By slightly twisting the neck of the rubber balloon, the bottom part of the water column is isolated from the majority of the water volume remaining in the tube. In the upper part there are most of the motile organisms. After separation and fixation in 4% buffered formaldehyde, the motile and non-motile individuals are counted separately.

Commonly used methods were applied for zooplankton investigations and species identification (Damian-Georgescu, 1963, 1966; Negrea, 1983; Rudescu, 1960; Wetzel, 2001).

In this study we defined and used the non-motility index, I_N, (expressed in %), as the ratio between average abundances of non-motile organisms and average abundance for all organisms, motile and non-motile:

$$I_N = \frac{N}{M+N} \text{ x } 100 \qquad (1.1)$$

where N is the average abundance of non-motile individuals, and M is the average abundance of motile individuals.

3. RESULTS AND DISCUSSIONS

In the surrounding area of Cernavodă NPP cooling system we identified 44 taxa belonging to the following groups: Rotatoria primary and secondary consumers (Rot PC and Rot SC), Bivalvia veligers (Biv), Cladocera (Cld) and Copepoda primary and secondary consumers (Cop PC and Cop SC).

3.1. Zooplankton abundance on the Cernavodă NPP area

Zooplankton abundance in the study sites revealed an average of 4847 indiv. m^{-3}.

If we consider the influence of CNE cooling system we can identify three different sampling areas (Fig.2):

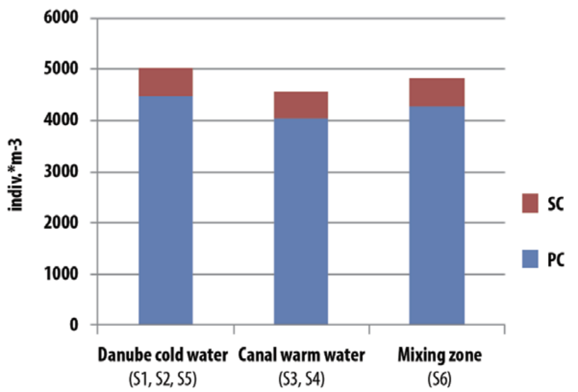

Fig. 2. Zooplankton structure in the sampling site groups

- Sites S1, S2 and S5 influenced only by the natural factors;
- Sites influenced by higher temperatures due to warm water evacuation (S3 and S4). Here, zooplankton organisms are aggressed not only by the temperature, but also by variations of pressure and other mechanical factors, along the cooling system;

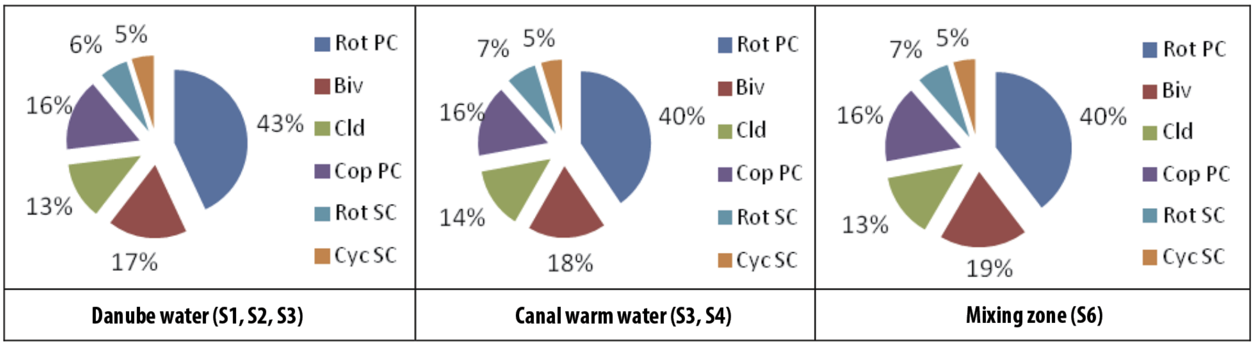

Fig. 3. Zooplankton structure on the field area [%]

- Site S6, in the area of mixing zone, where the cold Danube water is mixed with the canal warm water.

The highest values of abundance were found in the first group of sampling (cold Danube water) and the lowest in the canal warm water (Fig. 2). However, the percentage compositions of zooplankton groups in these three areas are similar (Fig. 3). This fact is revealed by Bray-Curtis similarity indices between the six sampling sites, which show a high degree of similarity inside each group and between the groups, too (Fig.4).

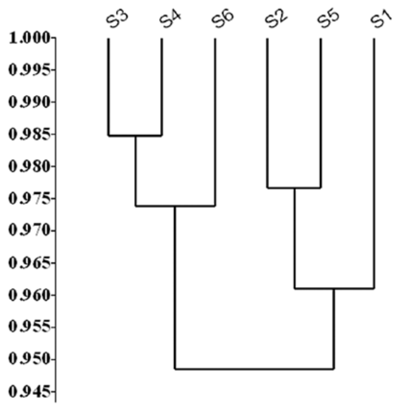

Fig. 4. Bray-Curtis similarity dendrogram

Evaluating the values of zooplankton abundance in the six sampling sites (Fig. 5), the following main features are highlighted:

- The water temperature had values ranging between 25.2⁰C on unaffected area to 33.6⁰C on warm water canal; in the mixing zone, the value of the temperature was about 29.3⁰C.
- Zooplankton abundance values in all three sampling points from unaffected area (S1, S2 and S5) were higher than the abundance values of zooplankton in warm water evacuated by the cooling system (S3, S4, on the downstream canal and S6, on the mixing zone).
- The highest value of abundance was recorded in site S2, before the cooling system (5094.6 indiv. m^{-3}), and the lowest was found in S4, at the end of the cooling system canal (4503.1 indiv. m^{-3}).
- There is a decreasing trend of zooplankton abundance along the S2-S3-S4 pathway, the difference between S2 and S4 being about 9.8%. For different groups, the abundance decreased between 6.5% for copepods primary consumers and 16.6% for rotifers primary consumers. A number of studies pointed out possible fragmentation of the organisms passing through the cooling systems (Kemp, 1977; Carpenter *et al*., 1974; Davies and Jensen, 1975; Evans *et al*., 1986), which could explain the lower values of abundance in the effluent of Cernavodă NPP. To prove the above, more samples accurately distributed spatially, including the hydrodynamic features of the moving water, should be considered.
- In the mixing area of the warm water with the river water, the zooplankton abundance has values between higher values from unmixed Danube water and lower values in the discharge canal water.
- The rotifers group is the most abundant in all sampling points.
- The taxonomic structure is almost the same in the whole investigated area, this fact suggesting that the advective movement of zooplankton organisms entrained by the water through the cooling system is the dominant factor in this ecosystem. For this reason, the evaluation of the adverse effects on zooplankton cannot be made only by measuring the total abundance.

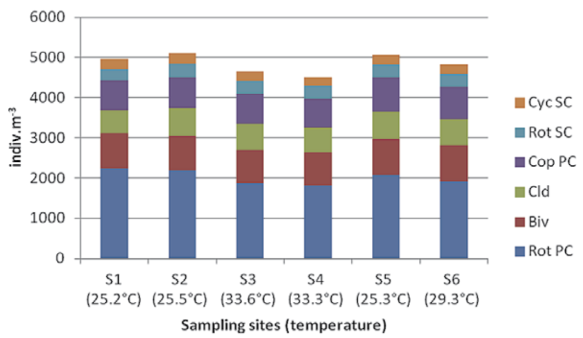

Fig. 5. Distribution of zooplankton group abundance

3.2. Adverse effects of Cernavodă NPP

Under normal conditions of the environment, zooplankton populations are characterised by a natural mortality rate which depends on the species. In the sampling points situated outside the influence of the cooling system (S1, S2 and S5), the index of mortality for individuals that die from causes other than predation is identified with the non-motility index described before.

Non-motility index measured at the outlet of the cooling system of nuclear power plant (S3 and S4) combines in its expression both natural mortality and the adverse effects of the cooling system (thermal and mechanical shocks).

Analysing this parameter in each sampling point, low values were found in stations that are not under the influence of the cooling system (S1, S2 and S5), and significantly higher values in stations on the hot effluent discharge (S3 and S4). Downstream the point of NPP effluent discharged in the Danube river (site S6), the non-motility index showed a value between the value found in the warm water canal (S4) and its value in the Danube station (S5) (Fig. 6). We found different non-motility index values for different zooplankton groups, but for each group these values were lower in the sampling points outside the NPP discharge water influence, and higher in the warm water.

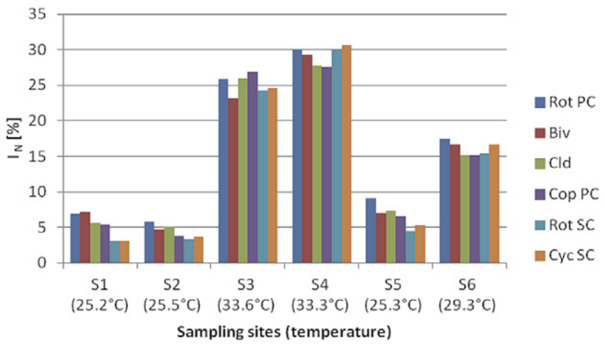

Fig. 6. Non-motilty index variation on the cooling system pathway [%]

In the case of the rotifers primary consumers this indicator ranged in the natural areas (S1, S2 and S5) between 5.7% (S2) and 9.04% (S5). In S3, an increase value up to 25.9% was recorded. The maximum I_N value was found in S4 (30.1%). In the mixed zone of warm effluent with the Danube cold waters (S6), this index was 17.4%.

For Bivalvia veligers, the non-motility index ranged between 4.71% (S2) and 7.2% (S1), in natural areas. The value of this index reaches up to 23.2% in S3, with a maximum value in S4 (29.2%), and in S6 was 16.7%.

Within the cladoceran populations, I_N ranged between 5.1% (S2) and 7.4% (S5), in natural areas. In comparison to S2, in S3, was recorded a value 5 times higher, with a maximum in S4 (27.8%).

The non-motility index for copepods primary consumers ranged in natural areas between 3.8% (S1) and 6.6% (S5). In the warm water I_N values were 26.6% in S3 and 27.6% in S4 sampling points. In the mixing zone (S6) a value of 15.2% was registered.

In the case of rotifers secondary consumers, non-motility index ranged in natural areas between 3.1% (S2) and 4.5% (S5). In S3 and S4 were recorded an I_N of 24.3% and 30.01% respectively. In the mixing zone, this parameter decreased to 15.4%.

In natural areas (S1, S2 and S5), cyclopoid copepods secondary consumers (Cyc SC) populations showed a non-motility index value between 3.2% (S1) and 5.4% (S5). In the warm water canal, the value reached up to 24.5% (S3) and 30.7% (S4) respectively, while, in the mixing zone, it decreased to 16.7%.

On average, the zooplankton index raised up from 6.2% in the unaffected zone to 29.3% on the warm water canal.

4. CONCLUSIONS

The adverse influences of Cernavodă NPP can be noticed in the abundance variation of motile and non-motile zooplankton organisms in the water entrained by the cooling system.

In July 2010, studying the NPP adjacent aquatic area, there were lower values of abundance for all zooplankton groups in the warm water canal, than in the natural aquatic areas, probably caused by fragmentation.

The non-motility index was an efficient tool to evaluate the negative effects on zooplankton entrained by the water in the cooling system of the Cernavodă NPP. It had specific values for each area, depending on species and environmental conditions. This index revealed higher values in the warm water canal as compared to the values outside the cooling water influence.

REFERENCES

Bamber, R.N., Seaby, R.M.H. (2004). The effects of power station entrainment passage on three species of marine planktonic crustacean, Acartia tonsa (Copepoda), Crangon crangon (Decapoda) and Homarus gammarus (Decapoda). *Marine Environmental Research,* **57**: 281-294. Doi:10.1016/j.marenvres.2003.08.002.

Carpenter, E., Peck, B.B., Anderson, S.J. (1974). Summary of entrainment research at Millstone Point Nuclear Power Station, 1970 to 1972. In: L.D. Jensen (ed). Proceedings of the Second Workshop on Entrainment and Intake Screening. The Johns Hopkins University. Pp: 31-35.

Choi, K.H., Kim, Y-O., Lee, J-B, Wang, S-Y., Lee, M-W., Lee, P-G., Ahn, D-S., Hong, J-S., Soh, H-Y. (2012). Thermal impacts of a coal power plant on the plankton in an open coastal water environment. *Journal of Marine Science and Technology,* **20** (2): 187-194.

Damian-Georgescu, Andriana (1963). Copepoda. Fam. Cyclopidae (forme de apă dulce). *Fauna R.P.R.,* **4***,* Ed. Acad. R.P.R., (6):.204p

Damian-Georgescu, Andriana (1966). *Copepoda.Calanoida* – forme de apă dulce. *Fauna R.S.R.*, **4**, (8), 130 p.

Davies, R.M., Jensen, L.D. (1975). Zooplankton entrainment at three mid – Atlantic power plants. *J. Water Pollut. Contrl. Fed.*, **47** (8), p 21-36.

Evans, M.S., Warren, G.J., Page, D.I. (1986). The effects of power plant passage on zooplankton mortalities: eight years of study at the Donald C. Cook Nuclear Plant. *Wat. Res.,* **20** (6): 725-734.

Gladyshev, M.I., Dubovskaya, O.P., Gubanov, V.G., Makhutova, O.N. (2003). Short communication. Evaluation of non-predatory mortality of two Daphnia species in a Siberian reservoir. *Journal of Plankton Research*, **25**, 8: 999-1003.

Guvernul României (2008). H.G.1515/2008 privind emiterea autorizației de mediu pentru Societatea Națională Nuclearelectrica - S.A. - Sucursala CNE - Unitatea nr. 1 şi Unitatea nr. 2 ale Centralei Nuclearelectrice Cernavodă, *Monitorul Oficial al României*, anul 177 (XXI) – Nr. **7**, 2009.

Kemp, W.M. (1977). Energy Analysis and Ecological Evaluation of a Coastal Power Plant, 582 p.

Kirillin, G., Grossart, H.P., Tang, K.W. (2012). Modeling sinking rate of zooplankton carcasses: Effects of stratification and mixing. *Limnol. Oceanogr.,* **57**(3), 2012, 881–894, 2012. doi:10.4319/lo.2012.57.3.0881.

Marcy, B.C. Jr., Beck, A.D., Ulanowicz, R.E. (1978). Effects and impacts of physical stress on entrained organisms. In: J.R. Schubel, B.C. Marcy Jr., eds. Power Plant Entrainment: A Biological Assessment. Academic Press. 135-188.

Negrea, St. (1983). Cladocera Crustacea. *Fauna R.S.R.*, vol. **IV**, (12), Ed. Academiei R.S.R., 400 p.

Rudescu, L., (1960). Trochelminthes. Rotaria. *Fauna R.P.R.*, **II** (2), Ed. Acad.R.P.R., 1192 p.

U.S. Environmental Protection Agency (2004). National Pollutant Discharge Elimination System: Final Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities. Federal Register/Vol.69, No. 131. Rules and Regulations, 41576-41693.

Wetzel, G.R. (2001). Limnology. Lake and River Ecosystems – 3rd Edition. Academic Press, London, 1006 p.