Polish J. of Environ. Stud. Vol. 19, No. 3 (2010), 547-552

Review

Influence of Discharged Heated Water on Aquatic Ecosystem Fauna

Grażyna Wałkuska[1]*, Agnieszka Wilczek[2]**

[1]Sub-Department of Toxicology and Environmental Protection, Department of Preclinical Veterinary Sciences,
[2]Sub-Department of Veterinary Prevention, Institute of Biological Bases of Animal Diseases,
Faculty of Veterinary Medicine in Lublin,
University of Life Sciences in Lublin, Akademicka 12, 20-033 Lublin, Poland

Received: 25 May 2009
Accepted: 30 November 2009

Abstract

The problem of thermal water pollution is still relatively unknown in Europe. The development of industry, especially the power industry, causes the release of enormous amounts of heated water from cooling operations to aquatic ecosystems. The observations made here confirm that an increase in water temperature in a reservoir leads to changes in aquatic ecosystem function and affects reservoir animals. Water temperature is one of the factors that determine species occurrence. Changes in water temperature immediately change fauna distribution and, consequently, the trophic relationships in a given ecosystem. Changes in water temperature can create conditions suitable for introduced fauna and may exacerbate the activity of infectious disease and parasitic agents that can damage native fauna populations. Increasing water temperature can lead to more frequent infections in animals by affecting the animal's immune system and by influencing pathogenicity. Thermal pollution of water bodies is not ecologically neutral and needs more attention from European scientists, especially ecologists.

Keywords: temperature, post-refrigeration water, water ecosystem

Introduction

It is generally known that there is a close interdependency between living organisms and their environment. This principle is particularly evident among aquatic organisms living in a close relationship with their natural habitat – the aquatic ecosystem. The variability of aquatic ecosystems fauna is highly dependent on physical, chemical and biological parameters of the water body in which they live. Changes to this habitat are reflected by changes in species composition and, consequently, changes in the trophic web in the aquatic ecosystem. This article discusses the influence of heated water on aquatic fauna based on the available literature.

*e-mail: grazynawalkuska@up.lublin.pl
**e-mail: lupus33@interia.pl

What are Water Thermal Disorders?

The literature includes a lot of information on chemical water pollution (e.g. the occurrence of heavy metals or pesticides, etc.) as well as biological pollution (i.e. a particular sanitary state of water), whereas too little attention is given to physical water pollution, especially thermal pollution in Europe. The broadest definition of thermal pollution is anthropogenic activities that result in temperature changes in a water body (lake, stream, river, or ocean) [1, 2]. Temperature in water bodies can be changed naturally from solar energy absorption or through anthropogenic activities. Since water bodies absorb very little solar energy, it is assumed that its influence causes insignificant daily water temperature change (this process usually involves upper layers of lakes) [3, 4]. However, human activity such as the removal of riparian zone plants leads to increased solar energy absorption by water and an excessive increase in water temperature. Cutting down the trees on a stream in northern England, for example caused an increase in water temperature from 15ºC to 21.5ºC [3].

Among natural phenomena affecting water temperature change are sea currents. One of them is El Nińo – an irregular meteorological phenomenon causes periodic disturbance of the Earth's thermal balance (every two to seven years) lasting from one to two years. This phenomenon arises in the whole Pacific area and affects weather change all over the world [5]. At times when El Nińo does not occur the surface temperature of the Pacific Ocean in the equatorial zone is 6-8°C higher in the western Pacific than in the eastern Pacific [6, 7]. This temperature difference is mainly caused by an influence of winds that, in the equatorial zone of the Pacific, blow from the east and move warm surface waters in a western direction. This, makes the ocean level about 0.5 m higher on the Indonesian coast than on the coast of Ecuador [5]. In order to make up for the difference on the eastern Pacific Ocean, cold water from deeper layers comes to the surface and is referred to as upwelling. This cool and nutrient-rich water has a large influence on biological productivity in the eastern Pacific and, consequently, supports a large fishing industry [8]. However, during an El Nińo the winds weaken, which leads to an equal distribution of warm surface water masses across the whole equatorial Pacific Ocean. This in turn results in the reduction of upwelling and a radical decrease of biological life variety [9].

Naturally existent thermal pollution is not a new phenomenon in water environment. For millions of years in geothermally active world areas nearly boiling water has been getting out of geysers and hot springs and flowing into streams, rivers, and lakes [1]. These natural thermal discharges alter the temperature regimes over considerable areas. Maximum water temperature of the stream Hot Creek (California, USA) ranges from 93°C at the spring to 23°C 400 m. downstream [10, 11]. The amounts of water released from hot springs are different. For example, Florida's Silver Springs discharge about 21,000 litres of boiling water per second, whereas Hot Creek releases only about 240 litres per second [11, 12].

For many years water has been used for cooling in manufacturing processes such as during the manufacture of glass, paper, or metals [1]. Small quantities of the 'heated' water were released to the nearest water body. Along with the rapid development of industry in the 20th century, the volume of water used in cooling processes grew rapidly. Currently, the most adverse impact on temperature increase in water bodies is caused by the power industry, particularly nuclear plants. In the USA, electric plants are responsible for 80% of thermal pollution in water bodies [1, 2]. Water is used in the plant to keep the temperature of energy processing at the lowest possible level so as to increase electrical generating efficiency [13]. The electrical generating plant as Moss Landing is the largest such plant in California. Water used in the plant is obtained from Monterey Bay, used in the plant, and then released back to the bay 200 m. from the coast and 7 m below the sea surface. The temperature of the water leaving the plant is approximately 13ºC (12.9°C-18.6ºC) higher than the water obtained from the sea. The cooling water discharged to Monterey Bay amounts to about 4.56 billion litres daily [2].

An Influence of Thermal Water Pollution on Ecological Interactions in a Water Body

Opinions of power industry experts and ecologists vary as to the influence of cooling water on aquatic ecosystems. According to the Power Industry Institute cited on the website of Poland's Polaniec Plant, the cooling water discharged from the plant to the Vistula river does not cause any adverse change in the river's ecosystem. Moreover, the institute implies that the discharge results in increase oxygenation of the Vistula, which significantly hastens the process of its self-purification. However, other studies (e.g. the Konin Project conducted in the 1970s) clearly demonstrated that heated water discharges are not ecologically neutral. The Konin Project studied the biological impacts of cooling water discharges from two electric plants to a system of five lakes with artificially designed systems of interconnections of a total area of 1,100 ha [14]. The temperature of water discharged to the lakes ranged from 10.1°C to 35ºC at the release volume of 80 m³/sec [14]. The surface water temperature difference between the lakes 'heated' by the discharge and the control ones was as much as 13ºC in the December to June period, whereas in summer the difference was less, reaching about 9°C. However, water temperatures on the lakes' bottoms differed more. In summer the temperature differences reached about 20ºC and in winter about 9°C [14].

The impact of raised water temperature on living organisms is most frequently seen in the lowered dissolved oxygen saturation level of warmer water since dissolved oxygen levels are often a limiting factor for organism survival [15, 16]. The studies carried out by Domagała et al. showed a decrease of dissolved oxygen in water accompanied by an increase of temperature. This can lead to a lack of oxygen in a water body [17]. An increase of temperature together with water body's pollution by nutrients (e.g. nitrates, phosphorates) leads to eutrophication with the consequence that a given water body may run out of oxygen [18, 19]. Studies conducted during the operation of the Konin Project did not show any significant differences in the dissolved oxygen level and saturation in artificially heated and unheated water bodies [14]. The primary productivity (phytoplankton) in the lakes where 'heated' water was discharged was about 100% higher than in the lakes without cooling water discharge. The same relationship was found for zooplankton production [14].

The impact of increased water temperature on aquatic organisms is also dependent on the character of the discharge (constant, occasional, or recurring) as well as on the degree to which the water is heated. Long-lasting or recurring contact of organisms with heated water may lead to the development of thermotolerance. Studies of the coral *Acropora grandis* (with an optimum water temperature of

24-28°C) exposed to 30ºC showed change of its colour (fading) within two days of exposure. A second exposure to heated water (again 30°C) did not cause change of colour in *Acropora grandis* until 6 days from exposure. Thermoregulation in this species was achieved by the production of heat shock proteins (HSP) that protected it from the influence of higher temperatures [20, 21].

Water temperature has a significant influence on activity and life cycles in poikilothermic aquatic organisms. Temperature affects the speed of egg development and growth of offspring that, consequently, controls the number of generations in a year, period of growth, and effectiveness of an organisms'colony. Seasonal temperature changes are often a signal to begin development and allow for the synchronization of life cycle with seasonal changes in the environment. Eggs of the *Ephoron album* mayfly undergo diapause in the low temperatures of winter months. The signal to break diapause and resume growth is a temperature change during the seasonal change from winter to summer [22]. Laboratory studies have shown that the hatching success of eggs treated at -2°C was positively correlated to the duration of the exposure period. Eggs treated at 4°C and 10°C did not hatch until exposed in a secondary treatment to -2°C for an additional 14 days [23]. In the situation where water temperature in winter is raised without the sudden seasonal temperature change, development of *Ephoron album* eggs stops [22, 24]. The impact of higher temperature on an aquatic organisms is difficult to determine because a particular population has specific temperature tolerances. Only after this value is crossed can an impact be observed. The thermal requirements of a particular organism can vary for a variety of reasons such as latitude. Cryophilic fish (e.g. Stream trout) generally are not adapted to water above 22°C, whereas most thermophylic fish (e.g. pike, carp) have temperature tolerances reaching approximately 30°C. Changing thermal regimes in water bodies is one of the factors responsible for the successful introduction of new fauna species to Polish water bodies [25]. An example of this is the presence in Poland of the Pumpkinseed sunfish *Lepomis gibbosus* – a species originally living in the Mississippi basin of North America. In Poland it is present in the lower Odra area, especially in the waters heated with electric plants discharge [25]. The introduction of new, invasive fauna species always carries the risk of a decline in population numbers or extinction of some native species, hybridization with local species, or the introduction of new parasites and pathogens to which the native species have no immunity [25]. An example is the appearance of a new parasite species in the waters of Poland (Gdańsk Bay, Pomeranian lakes) as well as in other countries of the Baltic region. This nematode *Anguilicolla crassus* invades the gas bladder of European eels *Anguilla anguilla*. The nematode was originally observed in the waters of East Asia [26, 27]. It was determined that the parasite's occurrence is closely associated with the discharge of heated water from electric and power industry plants [28]. Scientists investigating mass mortality of eels infected with *Anguillicola crassus* in Hungary (Lake Balaton) demonstrated a positive correlation between high water temperatures and the parasite infection coefficient [27].

Studies clearly show the positive influence of a higher temperature on an aquatic organisms'growth coefficient. Higher temperature, to a point unique to each population, increases feeding activity and food absorption efficiency [29-31]. Temperature can also influence the metabolic rate of aquatic organisms [31]. According to The Van Hoff rule, a water temperature increase of 10°C results in 1.5-4 times faster chemical reactions and, consequently, faster physiological processes. In higher water temperature we can observe an increased respiration rate of organisms. This increased respiration rate raises the overall metabolic rate, which may have a negative influence on an organism, especially if food is scarce [30]. Temperature, by its indirect positive influence on body mass, affects also fertility, since body size and the number of laid eggs are positively correlated [32]. An increase in water temperature can also cause changes in the behaviour of fish-altering rhythms of migration or spawing. Most fish require a specific temperature range for spawing, sometimes preceded by a temperature increase or decrease. Any deviation from this required regime usually results in a cessation or failure of spawning behavior. In the fathead minnow *Pimephales promelas*, the number of eggs per female, the number of eggs per spawning, and the number of spawings per female all decrease with temperature above an optimum [33]. Fish are attracted to heated areas of a water body at the expense of reduced reproductive performance. In the Firehole river, brown trout *Salmo trutta* did not spawn successfully in the warmest waters. Their gonads did not mature and eventually degenerated [33]. Other studies made in Swedish and Lithuanian thermal effluent areas confirm that high temperature influenced the gametogenesis of female perch *Perca fluviatilis*, roach *Rutilus rutilus* and pike *Esox lucius* negatively, indicating reduced reproductive capacity [34].

Higher Water Temperature and Infectious Diseases Occurrence

The role of temperature as an immunomodulatory factor also was confirmed, as was temperature's influence on infectious disease occurrence in fish. Changes in the immune system can make an organism susceptible to diseases. In favourable conditions fish maintain a state of health by a complex system of specific and non-specific immune defence mechanisms [35]. Non-specific immunity, the first line of defence in fish, is very sensitive to sudden environmental changes and can lead to changes in the general performance of the immune system [36, 37]. Numerous tests carried out on fish kept in water with variable temperatures clearly showed the sensitivity of cells involved in an organism's non-specific defence to water temperature increase. Exposure to thermal stress (a sudden increase in temperature by 5°C) for the Japanese medaka *Oryzias latipes*, for whom the optimum temperature is 25°C, caused a decrease of macrophage activity, lower lysosomal activity of cells involved in phagocytosis, a drop in activity of non-specific cytotoxic cells (NCC) and, a decrease of the phagocytic index [38]. Similar results were obtained by testing the immunological response in the African tilapia *Oreochromis mossambicus* to a challenge by *Streptococcus iniae* at a high temperature [39]. The results pointed to a decrease of phagocytic activity, an oxygen explosion mechanism inside phagocytes, and the alternative complement pathway's activity under conditions of temperature increase above the physiological optimum for the species (>27°C) [39]. In the experiment, a decrease in the number of circulating blood cells, particularly of the lymphocytes, was determined [40]. An increase of water temperature had, however, a very positive influence on lysosome activity, which grew considerably, side by side with an increase of water temperature above 31°C [41, 42]. The specific immune mechanisms in fish seem to be dependent on the changing water temperature. Studies carried out on the Atlantic cod *Gadus morhua*, with an optimum breeding temperature of 7°C, showed that an increase of water temperature to 14°C, influenced a profile change in the proteins synthesized in the fish [43]. The quantity of synthesized proteins decreased as the temperature was increased to 14°C, but at the same time it was accompanied by an increase of IgM concentration (fish are characterized mainly by one isotype Ig identified as IgM) with simultaneous compensatory reduction of albumine levels [41]. Temperature change is the main stress factor in fish, and in the vertebrates the answer to stress is change of glucocorticosteroids level. Cortisol (the main glucocorticosteroid in fish) can lower the immunity of fish tissues to bacterial and fungal infections [38]. Experiments with an application of cortisol to fish caused a decrease of the number of circulating lymphocytes T and B, as well as a reduction of lymphocyte mitogenesis [38]. The frequency of fish infectious diseases occurrence in a thermally changeable environment seems to depend not only on immune mechanism efficiency but also on the influence of a higher temperature on the infection agent itself. Studies on lobsters *Pacifastacus leniusculus* and *Astacus astacus* infected with WSSV white spot syndrome virus in changeable temperature conditions, i.e. about 4°C, 12°C and 22°C, showed that the development of infection at 22°C was characterized by the highest mortality rate [44]. This state of affairs corresponds to an increased replication factor in a higher temperature as well as to weaker non-specific organism defence mechanisms [44]. Recently (in 2008) in the rivers of Pomerania, an increase of ulcer disease in fish was observed. The disease is caused by the bacteria *Aeromonas salmonicida* and scientists have claimed that an increase of water temperature, favourable for the development of the bacteria, is one of the reasons for its growing occurrence [45, 46]. In aquatic ecosystems, besides native organisms there may also be exotic pathogens to which native species may not have defenses. The presence in natural waters of natural allochtonic intestine bacteria (mainly of the coliform group) shows that the waters polluted with feces and that the presence of other disease causing microorganisms in the given water body is possible. This can threaten both human and animal health [47]. Fecal water pollution is dependent on the physical parameters of the environment as well as on biological interactions with native organisms [47]. Results of research [48-50] on the relationship between water temperature and the growth factor, as well as the metabolic change factor of fecal bacteria, proved a positive correlation between these parameters. It has been assumed that an increase in temperature of 10ºC increases the development rate of water microorganisms by a factor of five [49]. In water samples collected at regular intervals during one year from the Chesapeake Bay (an Atlantic Ocean bay in the middle of the U.S. coast) the cholera-causing bacterium *Vibrio cholerae* was more often recorded during warmer months of the year when water temperature reached values higher than 19ºC [48]. Also, more frequent recordings of *Vibrio cholerae* in the Ganges River (author's reference) and a higher mortality rate among the Bangladesh population was associated with an increase in water temperature in this environment [49].

Thermal pollution of water is neutral neither for organisms living in a given environment nor for humans. An increase of temperature in a given water body leads to changes in its fauna both by extinction of species that require a lower temperature and by introduction of new 'thermophylic' organisms. Such changes cause changes in the functioning of aquatic ecosystems. Thermal pollution also results in a faster development of microorganisms that affect the health of both aquatic organisms and humans who come in contact with the water.

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