Contemporary Agriculture, Vol. 72, No. 4 (2023): 216-223
DOI: 10.2478/contagri-2023-0029
UDC: 581.52

Review Paper

INFLUENCE OF ENVIRONMENTAL POLLUTION ON ANIMAL BEHAVIOR

ISSN 2466-4774
https://www.contagri.info/

RENATA RELIĆ[1*], *MIRJANA ĐUKIĆ-STOJČIĆ*[2]

[1]University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Belgrade, Serbia
[2]University of Novi Sad, Faculty of Agriculture, Trg Dositeja Obradovića 8, Novi Sad, Serbia
**Corresponding author*: rrelic@agrif.bg.ac.rs

Submitted: 11.09.2023.
Accepted: 23.11.2023.

SUMMARY

Animals, like humans, act according to physiological patterns of behavior that change in response to various internal and external stimuli. Environmental pollutants represent "negative" stimuli and stressors. Air pollution is among pollution sources that pose the greatest threat to the environment and all living organisms. Exposure to pollutants causes behavioral changes in animals and disruption of organ functions and structures, which are often identical to those of humans working or living under the same conditions as animals (e.g., on a farm or in a city). Aside from a shorter life span and possible premature death, there are some diseases which commonly occur as a result of the exposure. Symptoms indicative of a disease or irritation, such as coughing, lameness, diarrhea, eye discharge and the like, cause the animal to make movements (actions) that are not part of their normal physiological routine and are considered behavioral changes. Behavioral changes are the earliest indicator that the animal is suffering from physical or mental disorders that can negatively affect its health and, in the case of livestock, production results. Various animal species serve as indicators of pollution, and domestic animals, including farm animals, can also serve this purpose. Behavioral changes resulting from exposure to various pollutants include disorientation, problems interacting with humans and other animals, reproductive problems, respiratory, digestive symptoms, etc. This review compiled data from a number of studies on changes in animal behavior after short or long exposure to various environmental pollutants. The focus was on the effects of air pollutants on animals, which are of particular importance to humans as they share living or working space with the animals or breed them for economic interest.

Key words:
air pollution, behavior, animals, stress, health, production

INTRODUCTION

Animals, like humans, act according to physiological patterns of behavior that are manifested in one or a combination of the following behaviors: social behavior, kinetic behavior, reproductive behavior, feeding behavior, exploratory behavior, hygienic behavior (including excretion, thermoregulation, and comfort behavior), territorial behavior, reactivity, and behavior related to rest and sleep (Vučinić, 2006). Each type of behavior is manifested through different activities that are constantly changing: "overt" activities that can be detected by observation, such as walking, sleeping, vocalizations, eating, etc., and "covert" activities that can be detected by instrumental methods (physiological processes related to the functions of the brain, heart, and other organs controlled by the autonomic nervous system), such as fluctuations in blood pressure (Milojević Apostolović, 2012; Sam, 2013; Anon, 2021). A change in behavior can be temporary or permanent, and it is seen as a change in an individual's behavior compared to a previous behavior (Bandura, 1977). Behavioral changes are a response of the organism to internal or external stimuli (positive and negative), that is, to events within the organism or its environment. Symptoms that indicate illness or irritation, such as coughing, lameness, itching, diarrhea, ocular secretions and the like, cause the animal to make movements (actions) that are also considered behavioral changes.

Negative stimuli that cause behavioral changes act as stressors. Stressors include anything that the animal finds unpleasant or life-threatening and that it cannot anticipate or control (e.g., sudden noise or predators). They trigger a stress response that involves activation of neurological, endocrine, and immunological pathways, i.e., the sympathetic-adreno-medullary (SAM) axis, the hypothalamic-pituitary-adrenal (HPA) axis, and the immune system (Mifsud & Reul, 2018). This leads to physiological and behavioral changes to adapt the animal to the new situation, and this in itself is not harmful to the organism. However, depending on the type, intensity, and the number of stressors acting simultaneously, the duration of exposure, or the animal's condition, the stress response may become maladaptive and harmful to the animal's organism (Broom & Kirkden, 2003; Temple et al., 2013).

Changes in common behavior patterns may indicate that the animal feels physical or mental discomfort. It is particularly the case with chronic stress, which affects the health and welfare of the animal, its response to humans and other animals, and, in the case of farm animals, production results (Relić et al., 2012, 2014, 2016, 2019; Relić & Vuković, 2013; Beaupied et al., 2022). For example, changes in behavior in dogs and cats and a decrease in dairy cow production were observed from a few minutes to 6 days before the earthquake (Yamauchi et al., 2014). Pets fled their normal environment or were frightened and stayed close to their owners. Dogs barked and/or howled and cats frequently vocalized. They were restless, trembled a lot, tried to hide somewhere or wanted to be in a different place than usual; they had no appetite and/or they had diarrhea and/or vomited. In rare cases, the animals also became aggressive. The milk yield of dairy cows on a farm 340 km from the epicenter decreased four to six days before the earthquake. All this was caused by the animals perceiving anomalies before the earthquake, such as electromagnetic signals and abnormal sounds, etc. (Yamauchi et al., 2014).

Behavioral changes may also occur as a result of exposure of the organism to pollutants. A pollutant may be a chemical substance (toxic metals, radionuclides, organophosphorus compounds, gasses, etc.) or geochemical substance (dust, sediment), a biological organism or product (bacteria, viruses, etc.), or a physical substance (heat, radiation, sound waves) that is intentionally or accidentally released by humans into the environment and has actual or potential harmful, unpleasant, or nuisance effects. Environmental pollution can be classified as air pollution, water pollution, land pollution, noise pollution, radioactive pollution, light pollution, thermal pollution, and so on.

Pollutants are environmental stressors (Jacquin et al., 2020). Aquatic organisms, insects, etc. are regularly used as bioindicators of environmental pollution (Zaghloul et al., 2020). Sievers et al. (2019) found that insecticides increase the frequency of abnormal swimming and reduce escape responses to simulated predator attacks in amphibians. Small fluctuations in air quality force certain insects to relocate, affecting other plants and animals that associate with them. Animals may relocate to a cooler location (if thermal pollution is present) or quieter location (if noise pollution is present). And light pollution can negatively affect nocturnal animals and disrupt seasonal movements, such as migration, as well as daily movements (Brown et al., 2023; Burt et al., 2023).

Domestic animals, including livestock, can also serve as biological indicators of pollution (Newman, 1975). Very similar pathomorphological, as well as behavioral changes are often observed in humans living or working in the same polluted environment as animals (Catcott, 1961; Beaupied et al., 2022). In this review, we summarize data from a number of studies on changes in animal behavior following exposure to some environmental pollutants. In the following text, the focus is on animal species that humans raise for economic or emotional reasons.

EFFECTS OF AIR POLLUTANTS ON ANIMAL BEHAVIOR

Air pollution is the biggest threat to the environment and all living organisms (Rhai, 2015) because pollutants from the air can contaminate all surfaces (water, soil, plants, etc.). There is a long list of air pollutants, the most important of which include carbon monoxide (CO), ammonia (NH_3), nitrogen oxide (NO), nitrogen dioxide (NO_2), ground-level ozone (O_3), particulate matter (PM), sulfur dioxide (SO_2), and volatile organic compounds (VOC) (Heinecke, 2021; CDC, 2022). Pollutants can be carried by air currents to areas far from their point of origin. They may fall directly on land and water surfaces (“direct” deposition) or they may run off contaminated land and enter downstream waters (“indirect” deposition). Deposition can occur in wet or dry forms. Wet deposition includes rain, snow, sleet, hail, or fog, while dry deposition includes gasses, dust, and particulate matter. Chemicals deposited in aquatic ecosystems can re-volatilize and be further dispersed through the atmosphere. In the atmosphere, pollutants can also be converted to other chemicals, some of which are more significant than those originally released into the atmosphere. Conversion to other chemicals can occur when pollutants are deposited and migrate through watersheds (Swackhamer et al., 2004).

Air pollution can cause animals to change their behavior in several ways. For example, it can cause birds to sing less or bees to leave their hives, or it can alter the migration patterns of some animals (Penque, 2023). Some animals, such as dairy cows, do not immediately respond with significant behavioral changes to poor air quality, but these conditions affect milk quantity and quality (Beaupied et al., 2022).

Effects of smog

Interest in the effects of air pollution on animals has generally evolved from concerns about its effects on human health, which began in the early 20th century (Beaupied et al., 2022). Several air pollution disasters resulted in apparent deaths and illnesses in humans as well as in pets and farm animals (Catcott, 1961). In the smog incident in Donora, USA (1948), hydrogen fluoride and sulfur dioxide emissions from two steel plants were trapped in a layer of colder air near the surface. Harmful compounds formed in the air (sulfuric acid, nitrogen dioxide, fluorine, and other toxic gasses) mixed with fog and hung over the city for five days until the rain ended the weather situation (McPhee, 2023). Dogs were the most susceptible species and reacted with three syndromes. The respiratory syndrome was the most common, and it was manifested as coughing, sneezing, conjunctival congestion, dyspnea, and nasal discharge. The digestive syndrome occurred with vomiting, retching, and diarrhea. The third syndrome was manifested as anorexia, which occurred with or without lassitude. With the exception of fatal cases, the disease lasted three to four days in dogs. Death also occurred in some cats, cattle, and poultry in Donora, after a short period of illness with symptoms similar to those in dogs. The predominant symptom in cows was coughing (Catcott, 1961).

Sunlight, nitrogen oxides, and volatile organic compounds in the atmosphere can produce a "photochemical smog" in a chemical reaction characterized by formation of highly toxic ozone. This type of smog is often referred to as summer smog (or Los Angeles smog) because it is more common in sunny urban areas with a large number of cars (Britannica, 2023). This pollution was associated with eye irritation and upper digestive tract irritation in dogs and pet birds in Los Angeles in 1954 (Catcott, 1961). In addition, Dey et al. (2023) found that the rate of dogs biting humans in urban areas increased with increasing temperature and ozone exposure (and higher UV irradiance). Ozone is not thought to cross the membranes of the respiratory tract and lungs. Exposure to ozone triggers the release of several neurotransmitters and activation of the HPA axis. Thus, behavior may be influenced by a general stress response to pollutants triggered by inflammatory second messengers in the lungs, but also by effects on the brain. Frequent exposure to small doses of ozone, which occurs in days with high levels of air pollution, leads to a state of chronic oxidative stress. As a result, changes occur in neuronal tissues, leading to alterations in learning and memory mechanisms, death of neurons, and loss of brain repair capacity (Bello-Medina et al., 2022; Baumann et al., 2023; Dey et al., 2023). Ozone can also induce an inflammatory response in the central nervous system (Guxensa & Sunyera, 2012). Neuroinflammation in brain tissue can trigger increased aggression and impulsivity (Xu et al., 2021), but also depression (Troubat et al., 2021). Therefore, dogs, similar to humans, may behave more aggressively on hot, sunny, and smoggy days.

The damage to neurons caused by particulate matter, especially in fetuses and infants, can lead to permanent brain damage or neurological disorders in adulthood (Santos et al., 2021). In a comparative study by Calderón-Garcidueñas et al. (2008), children with no known risk factors for neurological or cognitive disorders who lived in a polluted urban environment had significant cognitive deficits. Fifty-six percent of the children tested from Mexico City had hyperintense lesions of the prefrontal white matter, and similar lesions were also observed in dogs from the same city (57%). In another comparative study, epidemiological and animal data suggested that short-term exposure to air pollution can trigger nonspecific abdominal pain in young individuals (Kaplan et al., 2012).

Effects of air pollution on game and fish

Air pollutants can harm wildlife by disrupting endocrine function, damaging organs, increasing susceptibility to stress and disease, reducing reproductive success, and causing death (Newman, 1975). Fertility problems are a common behavioral consequence of exposure to air pollutants in wild animals in general. Basically, environmental pollution (e.g., from chemicals, light, heat, noise) can negatively affect animal communication and behavior – the signaling environment, and how animals produce, perceive, and interpret signals and cues. Such disruptions, especially during mating, can drastically alter the selection of a suitable mate. Environmental changes caused by pollution can directly affect individual mating decisions and mate choice. Environmental pollution that affects the behavioral, morphological, and physiological characteristics of individuals can alter mating rates. Environmental pollution can influence investment in mate choice through effects on food intake, metabolism, body condition, and mate-seeking motivation (Candolin & Wong, 2019).

Mercury is one of the most harmful pollutants to which fish and wildlife are exposed. This pollutant can be released into the atmosphere by incineration of household waste, burning of high-sulfur coal (containing cinnabar, HgS) in coal-fired power plants, metal smelting, chlor-alkali plants, cement production, and gold mining, and use of mercury-based fungicides in latex paints and in the pulp and paper industry. Monomethylmercury (MMHg) is the most toxic form of mercury, resulting from the transformation of mercury by microbial activity in lakes or wetland sediments. MMHg diffuses into the water column. When ingested by fish, it accumulates in their muscle tissue. Negative effects on reproduction have been documented in fish, fish-eating wildlife, and humans (Swackhamer et al., 2004). Fish have difficulty schooling (a behavioral strategy for protection from predators in which all fish move together in the same direction, at the same speed, and at the same time) and less success in spawning. Exposed birds lay fewer eggs and have problems raising their chicks. In mammals, motor skills are impaired, affecting their ability to hunt and find food (NWF, 2023). All of these impacts combined pose a serious threat to wildlife survival.
Mercury concentrations increase with each stage of the food chain. As a result, large predatory fish, such as trout, can have mercury levels more than a million times higher than the surrounding water. Humans and wild animals that consume fish or other species with high mercury levels are, in turn, at risk of serious health problems (NWF, 2023). Mercury causes neurological, liver, and kidney damage, as well as adverse effects on neurodevelopment in children (Swackhamer et al., 2004)
Many contaminants affect the cognitive performance of fish, with possible cascading effects on fitness, i.e., the ability of organisms to survive and reproduce. For example, aluminum contamination impairs the learning ability of Atlantic salmon Salmo salar, with serious consequences for the fish's ability to learn and remember information to escape predators, find food and mates, and avoid polluted areas and food (Jacquin et al., 2020). Effects of pollutants on courtship include a decrease or increase in the frequency of courtship, a longer duration of courtship, or the performance of male-like behaviors by masculinized females. Effects on parental care include decreased activity in nest building, decreased defense of offspring, or changes in the allocation of parental care between the sexes (Jones & Reynolds, 1997). Various compounds, such as surfactants, metals and pesticides, can damage the chemoreceptors and olfactory function of fish (Michelangeli et al., 2022).
In recent years, special attention has been paid to research on the effects of microplastics (MPs) on humans and animals. Due to the small size of the particles (< 5 mm), MPs are rapidly spread by wind and water. As a result, the particles are found in the air, soil, water, polar ice, deep ocean, and living organisms (Fackelmann & Sommer, 2019). MPs are often carriers of other pollutants, such as heavy metals (HMs). MPs can not only increase the accumulation of HMs in bodies, but also affect feeding-related movements, avoidance behavior, and swimming ability of fish when HMs are present. For example, fish may show drowsiness and unstable swimming, signs of rapid fatigue, decreased swimming speed, inhibited hunting ability, etc. (Chen et al., 2023).

Effects of indoor air pollutants

The air in livestock facilities often contains elevated concentrations of carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3), hydrogen sulfide (H_2S), and other harmful gasses that, together with increased humidity, dust, and high temperature, create very poor environmental conditions (Hristov & Relić, 2001; Buoio et al., 2023). Workers in animal facilities are exposed to the same increased levels of gasses, or the dust particles from feed and manure as the animals (Pickrell, 1991).
NH_3, H_2S, volatile organic compounds (VOCs), and other compounds can contribute to odors in livestock facilities. Odor is a nuisance and it is primarily related to human health concerns. However, Arnold et al. (1980) found that some odors from hay significantly affect sheep feeding behavior. Even if not toxic, odorous gasses can cause respiratory distress, decreased food intake, nausea, and psychological stress, which can lead to mental disorders in humans and anxiety and decreased productivity in animals (Hristov & Relić, 2001). For this reason, air pollution in livestock operations is generally considered a health risk, a stressor that can affect animal welfare. It also affects the health of farm workers and can affect workers' satisfaction with their job, which is inversely proportional to the welfare of the animals (Ni et al., 2021). The adverse effects of air pollutants on livestock workers are mainly associated with respiratory and cardiovascular diseases (Buoio et al., 2023).
Carbon dioxide is an odorless gas which is produced, among other ways, by the body's metabolism and it is a normal component of exhaled air. CO_2 concentrations in normally operated barns for livestock with minimal ventilation can exceed 6,000 ppm in winter (Ni et al., 2021), while the recommendation is to stay below 3,000 ppm. During prolonged stays in the barn with elevated CO_2 concentrations, animal productivity initially decreases, respiration becomes noticeably deeper and more frequent during rest, and animals experience dizziness and unconscious at high concentrations. CO_2 causes death by asphyxiation at a concentration of 30,000 ppm (Buoio et al., 2023).

Carbon monoxide (CO) is also an odorless, nonirritating gas produced by incomplete combustion of carbonaceous fuels (from unventilated kerosene or propane heaters, gasoline engines, automobile exhaust, or fumes from carbon-based fuel heating systems). CO binds to hemoglobin, preventing it from absorbing oxygen, resulting in hypoxia and cognitive impairment. The occurrence of headaches in humans is significantly related to exposure to CO and NOx (Xu et al., 2021). Depending on the concentration and duration of exposure to CO, animals may experience the following symptoms: drowsiness, weakness, lethargy, respiratory distress, seizures, abortions in pregnant animals especially in late gestation, depression, deafness, uncoordinated movements, coma, and death. Symptoms of chronic exposure to lower concentrations of CO include: nausea, hyperacidity of the blood, vomiting, cough, flu-like symptoms, loss of physical performance, gait disturbance. Newborn piglets exposed to high concentrations of carbon monoxide (250 ppm) take longer to nurse for the first time and have a poorer ability to orient, maneuver, and explore their surroundings (Morris et al., 1985). CO poisoning in dogs may be manifested by sudden or unusual behavior, such as aggression (toward children and other animals) or timidity (more fearful of noises), resistance or refusal to enter the house after being outside, vomiting, uncoordinated movements, drowsiness, difficulty breathing, unusual intolerance of exercise in which they normally participate, with bright cherry red lips, ears and gums (Anon., 2009).

Hydrogen sulfide most commonly occurs in the highest concentrations in swine barns, especially those with underfloor slurry pits. Dairy facilities generally have higher H_2S concentrations than poultry facilities. This gas is toxic and can be lethal in high concentrations, often leading to sudden illness, injury, or death (Ni et al., 2021). Exposure to a low concentration of H_2S causes headache, fatigue, and irritation of the mucous membranes of the eyes, nose, and throat. Repeated exposure could increase human and animal susceptibility to this gas. Death of animals and humans in livestock facilities has been noted after exposure to higher concentrations of H_2S (Liu et al., 2017).

Concentrations of ammonia and dust are the highest in poultry houses, followed by pig houses and cow barns (Ni et al., 2021). NH_3 has a strong irritating effect and damages mucous membranes even in low concentrations. If they can choose, farm animals prefer to stay in an environment where ammonia concentrations are lower (Jones et al., 2005). The lowest detectable concentration of NH_3 is 5 ppm, but as little as 6 ppm can cause respiratory and visual system discomfort in humans. Animal productivity can be affected at concentrations as low as 11 ppm. The United States Environmental Protection Agency (EPA) considers that exposure to 35 ppm for only 10 minutes is safe for humans. Concentrations of 40–50 ppm NH_3 can cause headaches and nausea in humans, and loss of appetite and decreased productivity in animals. In animals, NH_3 concentrations of 100 ppm can cause sneezing, salivation and discomfort of the mucous membranes. Concentrations of 300 ppm or higher pose a direct threat to human health and life (Moshayedi et al., 2023).

In addition to direct effects, NH_3 also contributes significantly to the particulate matter fraction (PM2.5), which can penetrate deep into the lungs and cause long-term diseases (Wyer et al., 2022). Poor air quality in poultry houses with elevated NH_3 concentrations may be a trigger for the occurrence of damaging behaviors in laying hens, such as feather pecking (Relić et al., 2019; Michel et al., 2022). This is likely due to the fact that elevated ammonia levels are correlated with increased levels of stress hormones and possibly behaviors indicative of stress (Drake et al., 2010). Chronic exposure to elevated ammonia levels resulted in lower live weight gain in broiler chickens (Jones et al., 2005).

Dust concentrations are usually the highest in poultry and pig houses, followed by cattle barns. Dust alone has harmful and irritating effects. A combination of dust and acid gasses forms the finest and most dangerous particles (Ni et al., 2021; Buoio et al., 2023). Dusts of concern in livestock habitats include PM10 (particulate matter with a size of 10 µm and smaller), PM2.5 (particulate matter with a size of 2.5 µm and smaller), and TSP (total suspended particulate matter). The effect of dust is usually related to pulmonary lesions. In an outbreak of cough in pigs, it was called “dust disease” in the United Kingdom (Ni et al., 2021). Ambient air pollution, especially PM2.5, is positively related to somatic cell count (SCC) and negatively related to milk production in dairy cows (Beaupied et al., 2022).

CONCLUSION

Animals are exposed to environmental pollutants just as much as humans, and in some cases even more so. Although the sensitivity of animals to individual pollutants is not the same in all species, almost all pollutants can result in death of the animal, preceded by more or less noticeable changes in behavior, a decline in production, increased susceptibility to stressors and diseases, reduced reproductive success, damage to the respiratory system, neurological problems, etc. Changes in common behavior are the first sign that the animal is uncomfortable in the environment it is in and it should not be ignored. In environments where both people and animals are present, a change in animal behavior may indicate that these conditions are not suitable for people, either. This is especially true on farms where a certain air quality is considered normal (or at least unavoidable) under production conditions, and its importance to the animals is usually ignored by breeders because of the short life span of the animals.

Acknowledgements**:** This work was supported by the agreement on the realization and financing scientific research in 2023 between the Ministry of Science, Technological Development and Innovation of the Republic of Serbia and the Faculty of Agriculture of the University of Belgrade (contract number: 451-03-47/2023-01/200116).

Conflict of interest: The authors declare that they have no conflict of interest.

REFERENCES

Anon. (2009): Carbon Monoxide Toxicosis in Dogs. Available at: https://www.petmd.com/dog/conditions/respiratory/c_dg_carbon_monoxide_toxicosis (accessed at 27.07.2023)

Anon. (2021): Ponašanje životinja. Hrvatska enciklopedija, mrežno izdanje. Leksikografski zavod Miroslav Krleža. Available at: http://www.enciklopedija.hr/Natuknica.aspx?ID=49386 (accessed 21. 06. 2023).

Arnold G.W., Boer E.S.D., Boundy C.A.P. (1980): The influence of odor and taste on the food preferences and food-intake of sheep. *Crop & Pasture Science*, 31(3): 571-587.

Bandura A. (1977): Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*. 84(2): 191-215.

Baumann K.K., Liang W.S., Quaranta D.V., Wilson M.L., Asrat H.S., Thysell J.A., Sarchi A.V., Banks W.A., Erickson M.A. (2023): Effects of Ozone on Sickness and Depressive-like Behavioral and Biochemical Phenotypes and Their Regulation by Serum Amyloid A in Mice. *International Journal of Molecular Sciences*, 24(2): 1612.

Beaupied B.L., Martinez H., Martenies S., McConnel C.S., Pollack I.B., Giardina D., Fischer E.V., Jathar S., Duncan C.G., Magzamen S. (2022): Cows as canaries: The effects of ambient air pollution exposure on milk production and somatic cell count in dairy cows. *Environmental Research,* 207: 112197.

Bello-Medina P.C., Rodríguez-Martínez E., Prado-Alcalá R.A., Rivas-Arancibia S. (2022): Ozone pollution, oxidative stress, synaptic plasticity, and neurodegeneration. *Neurología* (English Edition), 37(4): 277-286.

Britannica (2023): Smog. T. Editors of Encyclopedia. Encyclopedia Britannica, Available at: https://www.britannica.com/science/smog (assessed 29.08.2023).

Broom D.M. & Kirkden R.D. (2003): Welfare, stress, behaviour and pathophysiology. In: *Veterinary Pathophysiology*. Iowa State University Press, Iowa, p.337-369.

Brown J.A., Lockwood J.L., Piana M.R., Beardsley C. (2023): Introduction of artificial light at night increases the abundance of predators, scavengers, and parasites in arthropod communities. *iScience*, 26(3): 106203.

Buoio E., Cialini C., Costa A. (2023): Air Quality Assessment in Pig Farming: The Italian Classyfarm. *Animals,* 13(14): 2297.

Burt C.S., Kelly J.F., Trankina G.E., Silva C.L., Khalighifar A., Jenkins-Smith H.C., Fox A.S., Fristrup K.M., Horton K.G. (2023): The effects of light pollution on migratory animal behavior. *Trends in Ecology & Evolution*, 38(4): 355-368.

Calderón-Garcidueñas L., Mora-Tiscareño A., Ontiveros E., Gómez-Garza G., Barragán-Mejía G., Broadway J., Chapman S., Valencia-Salazar G., Jewells V., Maronpot R.R., Henríquez-Roldán C., Pérez-Guillé B., Torres-Jardón R., Herrit L., Brooks D., Osnaya-Brizuela N., Monroy M.E., González-Maciel A., Reynoso-Robles R., Villarreal-Calderon R., Solt A.C., Engle R.W. (2008): Air pollution, cognitive deficits and brain abnormalities: a pilot study with children and dogs. *Brain and Cognition*, 68(2): 117-127.

Candolin U. & Wong B.B.M. (2019): Mate choice in a polluted world: consequences for individuals, populations and communities. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences*, 374:20180055.20180055.

Catcott E.J. (1961): Effects of air pollution on animals. In: *Air Pollution*, World Health Organization: Monograph Series, No. 46, Geneva, 221-231.

CDC (2022): Centers of Disease Control and Prevention. Air Pollutants. National Center for Environmental Health. Available at: https://www.cdc.gov/air/pollutants.htm (accessed 18.07.2023).

Chen Q., Zhao H., Liu Y., Jin L., Peng R. (2023): Factors Affecting the Adsorption of Heavy Metals by Microplastics and Their Toxic Effects on Fish. *Toxics*, 11: 490.

Dey T., Zanobetti A., Linnman C. (2023): The risk of being bitten by a dog is higher on hot, sunny, and smoggy days. *Scientific Reports*, 13: 8749.

Drake K.A, Donnelly CA, Stamp Dawkins M (2010): Influence of rearing and lay risk factors on propensity for feather damage in laying hens. *British Poultry Science*, 51(6): 725-733.

Fackelmann G. & Sommer S. (2019): Microplastics and the gut microbiome: how chronically exposed species may suffer from gut dysbiosis. *Marine Pollution Bulletin*, 143: 193-203.

Guxensa M. & Sunyera J. (2012): A review of epidemiological studies on neuropsychological effects of air pollution. *Swiss Medical Weekly*, 141: w13322.

Heinecke R. (2021): Major air pollutants, their impact and sources. Breeze Technologies. Available at: https://www.breeze-technologies.de/blog/major-air-pollutants-their-impact-and-sources/ (accessed 18.07.2023).

Hristov S. & Relić R. (2001): Unpleasant odors and harmful gases in animal production (in Serbian). Proceedings of the XII DDD Coference in environmental protection with international participation. 23 - 26 May 2001, Banja Junaković - Apatin, 197-202.

Jacquin L., Petitjean Q., Côte J., Laffaille P., Jean S. (2020): Effects of Pollution on Fish Behavior, Personality, and Cognition: Some Research Perspectives. *Frontiers in Ecology and Evolution*, 8: 86.

Jones J.C. & Reynolds J.D. (1997): Effects of pollution on reproductive behaviour of fishes. *Reviews in Fish Biology and Fisheries*, 7: 463-491.

Jones E.K.M., Wathes C.M., Webster A.J.F. (2005): Avoidance of atmospheric ammonia by domestic fowl and the effect of early experience, *Applied Animal Behaviour Science*, 90(3-4): 293-308.

Kaplan G.G., Szyszkowicz M., Fichna J., Rowe B.H., Porada E., Vincent R., Madsen K., Ghosh S., Storr M. (2012): Non-Specific Abdominal Pain and Air Pollution: A Novel Association. *PLoS ONE*, 7(10): e47669.

Liu S., Ni J., Radcliffe J.S., Vonderohe C. (2017): Hydrogen sulfide emissions from a swine building affected by dietary crude protein. *Journal of Environmental Management*, 204(1): 136-143.

McPhee A. (2023): Donora Death Fog: Clean Air and the Tragedy of a Pennsylvania Mill Town. University of Pittsburgh Press. doi:10.2307/jj.890689.

Mifsud K.R. & Reul J.M.H.M. (2018): Mineralocorticoid and glucocorticoid receptor-mediated control of genomic responses to stress in the brain. *Stress*, 21(5): 389-402

Milojević Apostolović B. (2012): *Psihologija*. Novi Logos. Beograd, Srbija.

Michel V., Berk J., Bozakova N., van der Eijk J., Estevez I., Mircheva T., Relic R., Rodenburg T.B., Sossidou E.N., Guinebretière M. (2022): The Relationships between Damaging Behaviours and Health in Laying Hens. *Animals*, 12(8): 986.

Michelangeli M., Martin J.M., Pinter-Wollman N., Ioannou C.C, McCallum E.S., Bertram M.G., Brodin T. (2022): Predicting the impacts of chemical pollutants on animal groups. *Trends in Ecology & Evolution*, 37(9): 789-802.

Morris G.L., Curtis S.E., Simon J. (1985): Perinatal Piglets Under Sublethal Concentrations of Atmospheric Carbon Monoxide. *Journal of Animal Science*, 61(5): 1070-1079.

Moshayedi A.J., Sohail Khan A., Hu J., Nawaz A., Zhu J. (2023): E-Nose-Driven Advancements in Ammonia Gas Detection: A Comprehensive Review from Traditional to Cutting-Edge Systems in Indoor to Outdoor Agriculture. *Sustainability*. 15(15): 1160.

Newman J.R. (1975): *Animal indicators of air pollution: A review and recommendations*. Corvallis, Ore., U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Rep. CERL-006. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/9101XA1U.PDF?Dockey=9101XA1U.PDF (accessed 11.07.2023).

Ni J.Q., Erasmus M.A., Croney C.C., Li C., Li Y. (2021): A Critical Review Of Advancement In Scientific Research On Food Animal Welfare-Related Air Pollution. *Journal of Hazardous Materials*, 408: 124468.

NWF (2023): National Wildlife Federation. Pollution. Available at: https://www.nwf.org/Educational-Resources/Wildlife-Guide/Threats-to-Wildlife/Pollution (accessed 02.08.2023).

Penque M. (2023): How Does Air Pollution Affect Animals: The Irreparable Damage to Wildlife. SeedScientific. Available at: https://seedscientific.com/environment/how-does-air-pollution-affect-animals/ (accessed at 30.07.2023)

Pickrell J. (1991): Hazards in confinement housing--gases and dusts in confined animal houses for swine, poultry, horses and humans. *Veterinary and human toxicology*, 33(1): 32-39.

Rhai P.K. (2015): *Biomagnetic Monitoring of Particulate Matter.* Chapter One - Particulate Matter and Its Size Fractionation. Elsevier Science.

Relić R., Hristov S., Joksimović-Todorović M., Davidović V., Bojkovski J. (2012): Behavior of cattle as an Indicator of their Health and Welfare. Bulletin UASVM, *Veterinary Medicine*, 69(1-2): 14-20.

Relić R. & Vuković D. (2013): Reproductive problems and welfare of dairy cows. Bulletin UASVM, *Veterinary Medicine*, 70(2): 301-309.

Relić R., Ardo L., Marković Z., Stanković M., Davidović V., Poleksić V. (2014): Feed quantity effect on carp juveniles'plasma protein and immunoglobulin levels. Proceedings of the International Symposium on Animal Science 2014, 23-25 September 2014, Faculty of Agriculture, Belgrade, Serbia, 404-410.

Relić R., Bojkovski J., Rogožarski D., Becskei Z. (2016): Hocks and hooves condition and changes in behaviour of dairy cows in tied system, Book of Abstracts, 15th International Symposium "Prospects for the 3rd Millennium Agriculture", 29th September - 1st October 2016, UASVM, Cluj-Napoca, Romania, 500.

Relić R., Sossidou E., Dedousi A., Perić L., Božičković I., Đukić-Stojčić M (2019): Behavioral and health problems of poultry related to rearing systems. Ankara Universitesi Veteriner Fakultesi Dergisi, 66(4): 423-428.

Santos N.V., Yariwake V.Y., Valle Marques K., Matera V.M., Laís F. (2021): Air Pollution: A Neglected Risk Factor for Dementia in Latin America and the Caribbean. *Frontiers in Neurology*, 12: 684524.

Sam N. (2013): Behavior. Available at: https://psychologydictionary.org/behavior/ (accessed 21.06.2023).

Swackhamer D.L., Paerl H.W., Eisenreich S.J., Hurley J., Hornbuckle K.C., McLachlan M., Mount D., Muir D., Schindler D. (2004): Impacts of Atmospheric Pollutants on Aquatic Ecosystems. *Issues in Ecology*, 12: 1-26.

Sievers M., Hale R., Parris K.M., Melvin S.D., Lanctôt C.M., Swearer S.E. (2019): Contaminant-induced behavioural changes in amphibians: A meta-analysis, *Science of the Total Environment*, 693: 133570.

Temple D., Mainau E., Manteca X. (2013): Stress in farm animals. FAWEC, Technical documents. Available at: https://www.fawec.org/en/technical-documents-general-concepts/107-stress-in-farm-animals (accessed 11.07.2023)

Troubat R., Barone P., Leman S., Desmidt T., Cressant A., Atanasova B., Brizard B., El Hage W., Surget A., Belzung C., Camus V. (2021): Neuroinflammation and depression: A review. *European Journal of Neuroscience*, 53(1): 151-171.

Vučinić M. (2006): *Ponašanje, dobrobit i zaštita životinja*. Fakultet veterinarske medicine, Beograd, Srbija.

Wyer K.E., Kelleghan D.B., Blanes-Vidal V., Schauberger G., Curran T.P. (2022): Ammonia emissions from agriculture and their contribution to fine particulate matter: A review of implications for human health. *Journal of Environmental Management*, 323: 116285.

Xu A., Liu C., Wan Y., Bai Y., Li Z. (2021): Monkeys fight more in polluted air. *Scientific Reports*, 11: 654.

Yamauchi H., Uchiyama H., Ohtani N., Ohta M. (2014): Unusual Animal Behavior Preceding the 2011 Earthquake off the Pacific Coast of Tohoku, Japan: A Way to Predict the Approach of Large Earthquakes. *Animals* (Basel), 4(2): 131-145.

Zaghloul A., Saber M., Gadow S., Awad F. (2020): Biological indicators for pollution detection in terrestrial and aquatic ecosystems. *Bulletin of the National Research Centre*, 44: 127.