World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

Check for updates

Comprehensive review of toxicological risks in wild game consumption

Bertin Mikolo [1,*], Lewis Raud Miamb [2] and Kedar Tsoumou [3]

[1] *Laboratory of Food Industrial Engineering, National Polytechnic High School, Brazzaville, Republic of Congo.*
[2] *Laboratory of Pharmacodynamics and Experimental Pathophysiology, Faculty of Sciences and Techniques, Marien Ngouabi University, Po Box 69, Brazzaville, Congo.*
[3] *Human Nutrition and Food Laboratory, Faculty of Sciences and Techniques, Marien University Ngouabi, Brazzaville, Congo.*

World Journal of Advanced Research and Reviews, 2024, 23(02), 2396–2417

Publication history: Received on 09 July 2024; revised on 21 August 2024; accepted on 24 August 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.23.2.2524

Abstract

The consumption of wild game meat, rooted in cultural traditions and increasingly favored as a natural food source, presents both nutritional benefits and toxicological challenges. While wild game offers a rich source of protein and essential nutrients, it also carries unique risks associated with environmental contaminants, naturally occurring toxins, and zoonotic diseases. This review provides a comprehensive analysis of these toxicological hazards, drawing from a wide range of scientific literature. It examines the origins of toxins in wild game, including heavy metals, pesticides, and other environmental pollutants, as well as the risks posed by animals' natural diets and traditional hunting methods. Additionally, the review addresses the public health implications of consuming contaminated wild game and offers strategies for mitigating these risks. By exploring the complex interplay between wild game consumption and toxicology, this review aims to inform both consumers and public health professionals, emphasizing the importance of safe practices in the handling and preparation of wild game meat to minimize potential health hazards.

Keywords: Wild game meat; Nutritional benefits; Toxicological hazards; Environmental contaminants; Food safety practices

1. Introduction

Wild game consumption, a practice deeply embedded in various cultural and traditional contexts, is increasingly recognized for its nutritional value and potential health risks [1]. While game meat is often viewed as a nutritious alternative to conventional livestock, offering high levels of protein and essential nutrients, it carries distinct toxicological risks [2–4]. These risks stem from environmental pollutants, naturally occurring toxins within the animals, and zoonotic diseases [4–7]. With a growing interest in sustainable and organic food options, there is a heightened need to thoroughly understand these risks, especially as wild games become more popular in both rural and urban comiunities.

This review aims to thoroughly explore the toxicological hazards linked to wild game consumption. By investigating the sources and effects of these toxins—whether due to environmental contamination, the animals' natural diet, or specific hunting practices—this review seeks to raise awareness among consumers and public health officials about the potential dangers and the necessary precautions. Drawing on a wide range of existing research, this review will detail the various toxicological risks, evaluate their impact on human health, and discuss approaches to minimize these risks, ensuring the safe consumption of wild game meat.

* Corresponding author: Bertin Mikolo

Copyright © 2024 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution Liscense 4.0.

2. Wild game: cultural value, risks, and safety

2.1. The cultural and nutritional significance of wild game

Wild games are an integral part of the diets and traditions of many indigenous and rural communities [8]. Valued for its nutritional benefits and cultural heritage, wild game provides a lean, protein-rich meat that is often lower in fat compared to farmed alternatives [9–11]. It is also a significant source of omega-3 fatty acids, which are essential for heart health and brain function, as well as essential minerals like iron, zinc, and phosphorus, which contribute to overall health and well-being [10,12].

The appeal of the wild game extends beyond traditional communities to modern, health-conscious individuals, gourmet chefs, and those focused on sustainability. For health enthusiasts, the wild game offers a nutrient-dense alternative that fits with a preference for lean, minimally processed foods. Chefs value its distinct flavors and textures, which can enhance diverse culinary creations [13]. Sustainability advocates appreciate wild game for its potential to mitigate the environmental impact associated with conventional meat production [14]. Hunting practices associated with wild games often support wildlife management and conservation, helping to maintain ecological balance and preserve natural habitats [15].

Despite its advantages, it is crucial to recognize and manage potential risks related to wild game consumption. Factors such as environmental contamination and improper handling can pose health hazards, making it important for consumers to follow safe practices when hunting, processing, and preparing wild game [16–18]. By addressing these risks, the cultural and nutritional benefits of the wild game can be enjoyed safely and responsibly.

2.2. Environmental contaminants in the wild game

Wild game is susceptible to accumulating environmental contaminants, including heavy metals such as lead, mercury, and cadmium, which can pose health risks [19]. These contaminants may arise from industrial pollution, mining activities, pesticides, and persistent organic pollutants (POPs) from agricultural practices [20–22]. Additionally, wild games may carry naturally occurring toxins that are harmful to humans, including those from toxic plants or seeds, venomous animals, and zoonotic diseases.

2.3. Impact of hunting practices on toxicological risks

Hunting practices play a significant role in the toxicological risks associated with wild games, particularly through the use of lead ammunition and improper meat handling, processing, and storage [23,24]. Proper field dressing, refrigeration, and cooking are vital to minimizing these risks and ensuring the meat's safety. Factors that influence toxicological risks include the game's habitat and environmental exposure, dietary habits, hunting methods, climate and seasonal changes, and the broader public health implications.

2.4. Health risks to consumers and safety measures

The health risks to consumers include exposure to heavy metals like lead and mercury, pesticides, naturally occurring toxins, and zoonotic diseases [5,25,26]. To mitigate these dangers, proper handling, cooking, and processing of wild game are crucial. Safety measures include effective techniques for field dressing and meat handling, maintaining appropriate temperatures, cooking wild game to recommended levels, and using alternatives to lead ammunition. Public education on these practices is essential to inform hunters and consumers about the safe handling and preparation of wild game.

2.5. Regulations and guidelines for safe consumption

Regulations and guidelines are critical in managing the risks of wild game consumption and providing standards for the handling, processing, and consumption of wild game meat. Adhering to these regulations ensures that the meat is safe for consumption and helps reduce health risks.

2.6. The importance of ongoing research and monitoring

Continued research and surveillance are essential to deepen our understanding and effectively manage the toxicological risks linked to the consumption of wild game. This includes identifying new contaminants, assessing how environmental changes impact toxin levels, and improving safety practices and guidelines.

3. Natural toxins in the wild game

3.1. Types of natural toxins

3.1.1. Plant-based toxins

Wild plants can produce various toxins or phytotoxins that accumulate in game animals consuming them [27–30]. Cyanogenic glycosides, present in plants like cassava and certain fruit seeds, release cyanide when digested, potentially leading to severe health issues such as respiratory problems, convulsions, or even death in animals [31]. Alkaloids, found in plants like nightshades and hemlocks, can cause a range of symptoms from mild digestive upset to serious neurological effects, depending on their concentration and type. Prolonged exposure to these toxins can result in chronic health problems for wildlife.

3.1.2. Mycotoxins

Mycotoxins are harmful substances produced by fungi that can contaminate plants or animal feed [32–35]. *Aspergillus* fungi create aflatoxins, which are highly toxic and carcinogenic, often found in stored grains and nuts. Fusarium fungi produce fumonisins and trichothecenes, which can damage the liver and weaken the immune system. When wild game consumers feed contaminated with these mycotoxins, they may suffer from acute poisoning or long-term health effects, such as stunted growth and increased vulnerability to diseases.

3.1.3. Bacterial toxins

Some bacteria generate toxins that can affect wild games or present risks to humans [36,37]. *Listeria*, a Gram-positive, rod-shaped, facultative anaerobe, is a significant pathogen affecting pregnant women, newborns, elderly individuals, and those with weakened immune systems. It spreads through contaminated food, particularly ready-to-eat products, and can incubate for up to 70 days. Prevention involves hygiene and antibiotics. *Clostridium botulinum* generates botulinum toxin, a substance responsible for causing botulism, which can result in serious neurological symptoms and may be life-threatening. *Salmonella* bacteria release toxins that result in severe gastrointestinal issues [38]. Wild animals exposed to these bacterial toxins may display symptoms of illness, impacting their health and survival. Furthermore, these toxins can be passed to humans via contaminated meat, leading to foodborne illnesses.

3.1.4. Venoms

Venoms from certain wild animals can be dangerous if ingested [39–41]. Venomous snakes, like cobras and vipers, inject toxins that can cause a range of effects, including damage to the nervous system, blood cells, or tissues. Insects such as bees and ants also produce venom that can trigger severe reactions. If the wild game encounters or consumes venomous creatures, they may experience symptoms related to this type of venom, including pain or systemic effects.

These symptoms can range from localized pain to more widespread systemic effects, depending on the nature of the venom. Consuming meat from animals that have ingested or been bitten by venomous species can pose health risks depending on the amount and type of venom involved.

3.2. Symptoms and effects of toxin exposure

3.2.1. Acute toxicity

Wild game exposure to high levels of toxins may show immediate signs of acute toxicity. Common effects of exposure to natural toxins include cancers, death, coagulation toxicity, tissue necrosis, inflammation, neurotoxicity, and changes in vascular activity or just changes in food quality like discolored or bitter tasting milk [27,40]. For example, cyanide poisoning can lead to sudden respiratory distress, seizures, and potentially death. Similarly, exposure to mycotoxins like aflatoxins can cause severe symptoms such as intense vomiting, diarrhea, and stomach pain. Acute toxicity often results in a quick and intense reaction, requiring immediate intervention to mitigate serious health effects or prevent fatalities.

3.2.2. Chronic toxicity

Long-term exposure to toxins, even in smaller amounts, can result in chronic toxicity in the wild game. Continuous exposure to substances like alkaloids or mycotoxins can lead to progressive health issues, including liver damage, neurological disorders, and compromised immune function [35,42]. Over time, animals may experience problems such as stunted growth, reproductive issues, or an increased vulnerability to diseases [43]. Chronic toxicity arises from persistent exposure, causing ongoing health problems that affect the animal's overall health and ability to survive.

3.3. Risk mitigation strategies

3.3.1. Proper cooking techniques

One of the best ways to minimize the risk of toxin exposure from the wild game is through cooking. High cooking temperatures can eliminate many harmful bacteria, toxins, and parasites found in meat. For example, cooking meat at recommended internal temperatures can neutralize bacterial toxins like those produced by *Clostridium botulinum* and *Salmonella*. Additionally, certain preparation techniques, such as boiling or slow cooking, can help break down or lessen the concentration of some plant-derived toxins or phytotoxins. Properly cooking meat not only ensures its safety but also improves its taste and digestibility.

3.3.2. Avoiding contaminated areas

Avoiding hunting or foraging in areas with known contamination is another crucial strategy to reduce the risk of toxin exposure. This includes steering clear of regions where plants with high levels of cyanogenic glycosides or alkaloids are common, or where fungi producing mycotoxins are prevalent. Observing wildlife behavior can also indicate potential contamination; animals that seem ill or act unusually may have ingested toxic substances. By carefully choosing hunting locations and paying attention to the condition of the game, hunters can significantly lower the chances of encountering meat contaminated with toxins.

3.3.3. Inspection and assessment

Regular inspection and evaluation of wild games before consumption is essential to further reduce the risk of toxin exposure. This involves visually inspecting and assessing the meat for signs of contamination, such as strange odors, discoloration, or unusual texture. Additionally, examining organs like the liver and kidneys can reveal signs of chronic toxicity, such as lesions or abnormal coloring. Traditional knowledge often includes methods for detecting contaminated meat, which can be very useful in assessing its safety. By conducting these checks, hunters and consumers can make informed decisions and avoid the dangers associated with toxic meat.

3.4. Traditional knowledge and practices

3.4.1. Indigenous knowledge

Indigenous communities hold extensive traditional knowledge that aids in identifying and mitigating the risks posed by natural toxins in wild game [44]. This knowledge, developed over many generations, includes techniques for recognizing toxic plants, animals, and environments through careful observation and experience. For example, these communities may avoid hunting in areas where toxic plants are prevalent or apply specific methods to detoxify certain meats. This information is often shared through oral traditions, aiding in the preservation and adjustment of vital survival strategies as environmental conditions change.

3.4.2. Folklore and rituals

Folklore and rituals play a crucial role in traditional approaches to managing toxins in the wild game. Many communities have myths and stories that act as cautionary tales, warning about the dangers of consuming certain plants or animals. These narratives often incorporate practical advice on avoiding toxins, presented in a way that is memorable and easily passed down through generations. Rituals, often performed before hunting or preparing meat, may be used to invoke protection or ensure the safety of the food. These practices not only strengthen community ties but also offer a cultural framework for the safe and respectful use of natural resources.

4. Environmental pollutants

4.1. Sources of environmental contaminants

Environmental contaminants arise from a variety of sources: each playing a role in polluting the environment in different ways. This section explores the main sources of these pollutants and their environmental impacts.

4.1.1. Industrial pollution

Industrial operations are a major source of environmental pollutants. Mining and resource extraction for minerals and oil release heavy metals, chemicals, and pollutants into the air, water, and soil. Additionally, chemical manufacturing processes contribute to pollution by emitting toxic by-products, including hazardous. The Chisso chemical plant incident in Japan entailed the discharge of hazardous materials, including mercury, from the Chisso Corporation's facility. These industrial pollutants can disperse widely, impacting ecosystems far from their original sources.

4.1.2. Agricultural practices

Agriculture is another significant source of environmental contaminants. The use of insecticides, rodenticides, bactericides, acaricides and herbicides in farming introduces harmful chemicals into the environment, contaminating soil and water systems [45]. These chemicals can persist, affecting non-target species and leading to soil degradation and water pollution. Fertilizers, although crucial for crop production, can cause nutrient runoff, which leads to eutrophication in water bodies. This process depletes oxygen levels in aquatic environments, resulting in serious harm to fish and other wildlife.

4.1.3. Natural sources

Environmental contaminants can also originate from natural processes. For instance, volcanic activity releases large amounts of gases, ash, and heavy metals into the atmosphere and surrounding areas [46]. Additionally, soil erosion and sedimentation, driven by natural forces like wind and water, can redistribute contaminants, such as naturally occurring heavy metals and minerals [47]. While these natural sources are part of the earth's natural cycles, they can pose significant environmental and health risks, especially when combined with human activities. Climate change is also causing shifts in food webs, lipid dynamics, ice and snow melt, and organic carbon cycling, which could lead to higher levels of persistent organic melting (POPs) in water, soil, and living organisms. Additionally, rising temperatures may have harmful effects on wildlife already exposed to these pollutants.

4.2. Impact of environmental contaminants on wildlife

Environmental contaminants have significant effects on wildlife, disrupting ecosystems and endangering various species. This section explores how these pollutants affect wildlife through bioaccumulation, habitat degradation, and their impacts on reproduction and development.

4.2.1. Bioaccumulation and biomagnification

Bioaccumulation and biomagnification are processes where environmental toxins, such as heavy metals and persistent organic pollutants, gradually build up in the bodies of wildlife. Animals at lower levels of the food chain ingest contaminated food or water, accumulating toxins in their tissues. Predators that consume these animals then experience even higher concentrations of these toxins [48]. Over time, as these toxins magnify through the food chain, top predators can suffer severe health consequences, including reproductive problems, weakened immune systems, and increased mortality.

4.2.2. Habitat degradation

Contaminants can also lead to habitat degradation, directly impacting wildlife. Pollutants from industrial, agricultural, and natural sources can degrade the air, water, and soil, resulting in a loss of biodiversity. Introducing toxins into aquatic ecosystems can disrupt species balance, leading to the decline or extinction of vulnerable species. Moreover, contamination can alter vegetation, reducing available food and shelter for wildlife. Habitat degradation may compel animals to migrate, encounter increased competition, or experience population declines.

4.2.3. Reproductive and developmental effects

Environmental contaminants can significantly harm wildlife reproduction and development. Toxins like endocrine disruptors can disrupt hormonal systems, causing decreased fertility, abnormal growth, and birth defects in offspring. For example, heavy metals such as lead and mercury can result in developmental delays, neurological damage, and behavioral changes in young animals [49]. These impacts can reduce the overall fitness of populations, making them more susceptible to other environmental challenges and potentially leading to population declines or extinction.

4.3. Human exposure to environmental contaminants

Humans can encounter environmental contaminants through various routes, which can result in severe health effects. This section outlines the main routes of exposure, including contaminated water sources, food chain contamination, and airborne pollutants [50–53].

4.3.1. Contaminated water sources

Contaminated water sources are a primary route for exposure to harmful substances. Heavy metals like lead, mercury, and arsenic, often resulting from industrial activities or natural occurrences, can taint drinking water, leading to serious health issues such as kidney damage, neurological problems, and cancer [54]. Water can be contaminated with organic pollutants and pathogens from agricultural runoff or poor waste treatment; resulting in gastrointestinal illnesses and other health problems. Ensuring access to clean water is essential to mitigate these risks.

4.3.2. Food chain contamination

Food chain contamination poses serious health risks to humans. Pesticides, herbicides, and heavy metals can accumulate in edible plants and animals, including game and fish. Consuming such contaminated food can result in health problems ranging from acute poisoning to chronic conditions like cancer and reproductive disorders.

Monitoring and regulating food contaminants is crucial for safeguarding public health and ensuring food safety.

4.3.3. Airborne contaminants

Airborne contaminants, such as particulate matter and persistent organic pollutants (POPs), are another key source of exposure [55]. Breathing in these pollutants, which can come from industrial emissions, vehicle exhaust, or waste burning, can lead to respiratory and cardiovascular issues, among other health problems. POPs, like dioxins and PCBs, can accumulate in the body over time, resulting in long-term health effects. Reducing air pollution through stricter regulations and better technologies is vital for protecting human health.

4.4. Mitigation and management strategies

Addressing environmental contaminants involves implementing a variety of strategies to reduce pollution, and protect ecosystems and human health. This section outlines key approaches to pollution control, sustainable practices, and community engagement.

4.4.1. Pollution control and remediation

Effective pollution control and remediation involve regulatory and technical measures. Regulatory frameworks establish standards and limits for emissions and waste discharges, ensuring industries follow practices that minimize environmental impact. Enforcement of these standards is crucial for maintaining environmental health. Remediation techniques like soil washing, bioremediation, and chemical treatment clean contaminated sites by removing or neutralizing pollutants, restoring them to safe conditions.

4.4.2. Sustainable agricultural practices

Sustainable agricultural practices play a key role in reducing environmental contamination. Integrated Pest Management (IPM) employs a combination of biological, cultural, and chemical methods to control pests while minimizing environmental harm [56]. Organic farming methods avoid synthetic pesticides and fertilizers, reducing the release of harmful substances into the environment. Additionally, techniques like crop rotation, conservation tillage, and proper nutrient management improve soil health and decrease runoff, lowering the risk of water contamination.

4.4.3. Community awareness and involvement

Raising community awareness and involvement is essential for effective environmental management [57]. Educational programs can help the public understand the sources and impacts of environmental contaminants, and how to reduce exposure [58]. Encouraging community participation in clean-up drives and environmental monitoring fosters collective responsibility. Local knowledge and traditional practices can also contribute to environmental stewardship, helping communities develop strategies suited to their specific conditions and needs.

4.5. Case studies: environmental pollutants

4.5.1. Minamata disease in Japan

Minamata Disease emerged in Japan in the 1950s due to severe mercury pollution in Minamata Bay [59]. The Chisso Corporation's release of mercury-laden wastewater into the bay contaminated local seafood, which was a staple in the diet of nearby communities. The resulting mercury accumulation in the food chain led to serious health issues, including neurological disorders, sensory impairments, and cognitive problems. This environmental disaster underscored the dangers of industrial pollution and prompted significant reforms in Japan's environmental and public health policies.

4.5.2. Flint water crisis in the USA

The Flint water crisis, which began in 2014, is a significant example of lead contamination impacting public health [60]. Flint, Michigan, switched its water supply to the Flint River to cut costs, but the river's corrosive nature caused lead to leach from old pipes into the drinking water. This resulted in elevated lead levels in residents' blood, especially affecting children, and led to various health issues like developmental delays and cognitive impairments. The crisis highlighted the need for better infrastructure and regulatory oversight to prevent such public health emergencies.

4.5.3. Bhopal gas tragedy in India

The Bhopal Gas Tragedy, occurring in December 1984, is one of the most devastating industrial accidents ever recorded [62,63]. A leak of methyl isocyanate (MIC) gas from a Union Carbide pesticide plant in Bhopal, India, created a toxic gas cloud that spread over the city. This caused immediate respiratory distress and long-term health issues, including chronic respiratory conditions and reproductive problems. The tragedy highlighted the critical need for improved industrial safety measures and emergency response planning.

4.5.4. Love Canal incident, New York, USA

In the late 1970s, the Love Canal incident in Niagara Falls, New York, brought national focus to issues with hazardous waste disposal. A residential neighborhood was constructed over an old toxic waste site, resulting in significant contamination of the soil and groundwater. Residents suffered from increased rates of cancer and birth defects, prompting environmental activism and the creation of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), known as the Superfund law, to address and remediate hazardous waste sites.

4.5.5. Contamination in the Amazon Rainforest, South America

The Amazon Rainforest has been significantly affected by environmental contamination from agricultural runoff and illegal mining [22,65]. The use of pesticides and fertilizers in agriculture has polluted waterways, while illegal mining introduces heavy metals like mercury into the environment. These pollutants have detrimental effects on local ecosystems, wildlife, and human health, impacting indigenous communities and the rainforest's crucial role in global climate regulation.

4.5.6. Chernobyl disaster in Ukraine

The Chernobyl disaster, which occurred in April 1986, was a catastrophic nuclear accident at the Chernobyl Nuclear Power Plant in Ukraine [66,67]. The explosion and subsequent fire released large amounts of radioactive particles into the atmosphere, affecting areas across Europe. The immediate health effects included acute radiation sickness and deaths among plant workers and emergency responders. Long-term consequences include increased thyroid cancer rates and other health issues in the affected regions, highlighting the risks associated with nuclear power and the importance of rigorous safety measures and disaster response strategies.

5. Toxic plants and secondary poisoning

5.1. Toxic plants

Toxic plants present a substantial risk to both natural ecosystems and human-altered environments due to their ability to harm various organisms [68,69]. These plants produce chemical compounds that interfere with physiological processes, leading to a range of effects from mild irritation to severe poisoning or even death. They thrive in diverse habitats and often develop toxins as a defense mechanism against herbivores or pathogens. The detrimental effects of these toxins can disrupt crucial bodily functions, including nerve transmission, cellular respiration, and digestion. Effective management of toxic plants requires comprehensive strategies for identification, prevention, and treatment.

By understanding their characteristics and impacts, we can create effective approaches to mitigate risks to both humans and wildlife.

5.1.1. Identification and characteristics

Toxic plants can be recognized by their distinctive physical and botanical characteristics, including unique leaf shapes, flower formations, or seed pods.. They thrive in specific environmental conditions, including dry, rocky soils and areas near water sources. Recognizing these characteristics is crucial for avoiding these plants and understanding their potential hazards.

5.1.2. Common toxic plants

Several plants are known for their toxic properties [70]. For example, *Strychnos* species contain strychnine, a neurotoxin that can cause severe convulsions and death if ingested. *Datura stramonium* (Jimsonweed) contains tropane alkaloids, which can lead to delirium, hallucinations, and potentially fatal poisoning. *Euphorbia* species produce milky sap with compounds that can irritate the skin and cause gastrointestinal distress if consumed. These toxic plants can harm wildlife through ingestion or contact and pose health risks to humans, ranging from mild irritation to severe poisoning depending on the plant and exposure level.

5.2. Mechanisms of toxicity

Understanding the mechanisms of toxicity is crucial for comprehending how toxic plants affect organisms. This section explores the types of toxic compounds found in plants and the routes through which poisoning occurs.

5.2.1. Types of toxic compounds

Toxic plants contain various harmful compounds that disrupt physiological processes [71]. Alkaloids, such as strychnine and nicotine, interfere with nervous system functions, causing severe effects like convulsions or paralysis. Glycosides, including cyanogenic glycosides, can release cyanide when metabolized, leading to respiratory failure and death. Saponins can damage cell membranes, causing gastrointestinal distress and hemolysis [72]. Terpenoids, including essential oils, can be harmful if ingested or absorbed, causing symptoms that range from mild irritation to serious organ damage. Each of these compounds has distinct mechanisms through which they produce their toxic effects. Each of these compounds has specific mechanisms by which they exert their toxic effects.

5.2.2. Routes of poisoning

Poisoning from toxic plants can occur through several routes [73]. Ingestion is the most prevalent route, with harmful substances being absorbed through the digestive system; resulting in systemic toxicity. Skin contact with toxic plant parts, such as sap or thorns, can cause localized reactions, including irritation or allergic responses. Inhalation of plant particles or vapors, particularly from volatile compounds in essential oils, can lead to respiratory issues or systemic effects. Understanding these pathways is crucial for identifying potential exposure risks and formulating effective preventive and treatment strategies.

5.3. Secondary poisoning

Secondary poisoning occurs when toxins are transferred through the food chain, affecting organisms that were not directly exposed to the original toxic sources [69,74]. This section explains what secondary poisoning is, how it happens, and its effects on ecosystems.

5.3.1. Definition and process

Secondary poisoning occurs when toxins from contaminated plants or prey accumulate in organisms that consume them. For example, herbivores that ingest toxic plants may carry these toxins in their bodies. When predators or scavengers eat these contaminated herbivores, they also ingest the toxins, leading to potential health problems. This transfer of toxins can significantly impact the health of top predators and disrupt ecological balance.

5.3.2. Impact on ecosystems

The effects of secondary poisoning on ecosystems can be severe, disrupting food chains and harming wildlife. As toxins move up the food chain, they can cause reproductive issues, behavioral changes, and increased mortality among predators and scavengers. This can lead to declines in predator populations, which then affects prey populations and overall ecosystem stability. Additionally, secondary poisoning can reduce biodiversity, as affected species may have trouble surviving or reproducing, ultimately altering the structure and function of the ecosystem.

5.4. Detection and management

Properly addressing the issues of toxic plants and poisoning involves effective detection and management strategies [75,76]. This section discusses how to identify poisoning incidents, the diagnostic methods used, and approaches for treatment and prevention.

5.4.1. Identifying poisoning incidents

Identifying poisoning involves recognizing the symptoms and employing diagnostic methods to determine the underlying cause. Symptoms can vary based on the toxin and may include gastrointestinal problems, neurological effects, or skin irritations. Initial detection often involves field tests to identify toxic plants and their effects, while laboratory tests provide more precise information about specific toxins. Diagnostic tools like blood tests, urinalysis, and tissue analysis are essential for confirming poisoning and guiding treatment decisions.

5.4.2. Treatment and prevention

Treatment of poisoning typically includes supportive care, along with targeted actions to counteract the effects of the toxins. First aid may include removing a source of exposure, administering activated charcoal to reduce toxin absorption, and addressing symptoms. Medical treatments might involve antidotes for specific toxins and therapies to support affected organs. Prevention efforts include educating people about toxic plants; encouraging safe practices in areas where these plants are found, and implementing controls to manage their spread. Public awareness and preventive strategies are vital for minimizing poisoning risks and safeguarding health for both people and wildlife.

5.5. Case studies: toxic plants and poisoning in the World

Examining global case studies of toxic plants and poisoning offers insights into their effects across different regions and populations. This section reviews significant incidents of poisoning, their impacts and their responses to these issues.

5.5.1. Documented incidents

Globally, toxic plants have caused major poisoning events affecting both humans and wildlife. For instance, *Ricinus communis* (castor bean) has led to severe poisoning in Africa; due to ricin, a powerful toxin. In South America, plants like *Brugmansia* spp. (Angel's trumpet), which contains atropine, has caused hallucinations and serious health issues. In Asia, poisoning from *Aconitum* spp. (monkhood) led to severe cases of cardiac and respiratory failure. These examples underscore the serious risks associated with toxic plants and the importance of effective preventive measures.

5.5.2. Traditional and modern responses

Responses to toxic plant poisoning worldwide often combine traditional and modern methods. Traditional methods for treating poisoning often include the use of specific herbs or detoxification techniques. For instance, activated charcoal is frequently used as an antidote in diverse cultural practices. Modern responses include medical treatments, such as antidotes and supportive care, along with public health campaigns to educate people about the dangers of toxic plants. Effective management usually requires a partnership between traditional healers and healthcare professionals, combining traditional knowledge with modern medical practices to address and reduce the impact of plant toxins.

6. Infectious agents and zoonotic diseases

6.1. Types of infectious agents

Infectious agents affecting the wild game globally can also pose substantial risks to human health. This section explores various bacteria, viruses, and parasites transmitted from wildlife to humans through direct contact or consumption of contaminated meat.

6.1.1. Bacteria

Bacterial pathogens in the wild game can lead to severe human infections. *Brucella* spp., which causes brucellosis, can be transmitted to humans through direct contact with infected animals or consumption of undercooked meat. This disease causes flu-like symptoms, and in severe cases, can lead to chronic health issues. *Mycobacterium bovis*, the bacterium responsible for bovine tuberculosis, can be transmitted to humans through unpasteurized dairy products or by coming into contact with infected animals; potentially leading to respiratory and systemic infections. Similarly, *Salmonella* spp., present in wildlife such as birds and reptiles, can be spread to humans through contaminated meat or contact with infected animals; resulting in gastrointestinal illness.

6.1.2. Viruses

Viruses affecting wild games can also infect humans, often with serious consequences. Hantavirus, carried by rodents like deer mice, can be transmitted to humans through contact with rodent droppings or urine; causing hantavirus pulmonary syndrome (HPS), which can lead to severe respiratory distress. The West Nile virus, transmitted by mosquitoes that have fed on infected birds, can affect humans with symptoms ranging from mild flu-like signs to severe neurological diseases. Ebola virus, carried by wildlife such as bats and primates, can be transmitted to humans through direct contact with infected animals or their bodily fluids; causing severe hemorrhagic fever with high mortality rates.

6.1.3. Parasites

Parasites from wild games can also infect humans, often through consumption or contact. *Toxoplasma gondii*, found in various wildlife such as deer and rodents, can be transmitted to humans through contact with infected meat or soil; leading to flu-like symptoms and severe complications in immunocompromised individuals. *Trichinella* spp., a parasitic roundworm found in wild carnivores such as bears and pigs, can infect humans through consumption of undercooked meat, causing trichinosis, which leads to gastrointestinal and muscular symptoms. *Echinococcus* spp., a tapeworm found in wild canids like wolves and foxes, can cause echinococcosis in humans through ingestion of eggs shed in the feces of infected animals, leading to potentially severe cystic infections in organs such as the liver and lungs.

6.1.4. Prions

Prions are infectious agents composed of misfolded proteins that cause various degenerative diseases in both wildlife and humans [79]. Unlike bacteria, viruses, or parasites, prions are not living organisms and do not contain nucleic acids. They propagate by inducing normal proteins in the host to adopt their abnormal, disease-causing shape. This section covers prion diseases in the wild game and their potential impact on human health.

Prions cause severe neurodegenerative diseases that affect the brain and central nervous system. Chronic Wasting Disease (CWD) is a notable prion disease affecting cervids such as deer, elk, and moose. CWD leads to severe weight loss, behavioral changes, and eventually death. The disease is of concern because it can potentially spread to other wildlife and domesticated animals. Bovine Spongiform Encephalopathy (BSE), also known as "mad cow disease," primarily affects cattle. However, it can be transmitted to humans through contaminated meat products, leading to variant Creutzfeldt-Jakob Disease (CJD), a fatal neurodegenerative condition. Infections with prions are difficult to diagnose and there are no effective treatments, making prevention and surveillance critical to manage these diseases and reduce their risk to human populations.

6.2. Zoonotic diseases

Zoonotic diseases are infections that can spread between animals and humans. This section examines the characteristics of zoonoses, their modes of transmission, and their impact on human health, including examples and case studies for illustration.

6.2.1. Overview of zoonoses

Zoonoses are illnesses that spread from animals to humans, either through direct contact with infected animals or indirectly via vectors such as ticks or mosquitoes [80]. These diseases can vary widely in severity, from mild symptoms to serious health conditions. They are particularly prevalent in areas where humans and animals live in close proximity, including agricultural areas, wildlife habitats, and urban settings where animal interactions are frequent.

6.2.2. Notable zoonotic diseases

Several zoonotic diseases are notable for their impact on human health [5]. Rabies, a viral disease spread through the bites of infected animals such as dogs, results in severe neurological symptoms and can be fatal if not treated. Brucellosis is a bacterial disease spread through contact with infected animals or consumption of unpasteurized dairy; causing flu-like symptoms and potential long-term health issues. Hantavirus Pulmonary Syndrome (HPS), transmitted through contact with rodent droppings or saliva, results in severe respiratory problems. Leptospirosis is caused by bacteria that are present in water contaminated by animal urine. It can result in symptoms ranging from mild flu-like illnesses to severe liver and kidney damage. These diseases illustrate the importance of monitoring and controlling zoonotic infections to safeguard human health.

6.2.3. Case studies and epidemiology

Examining case studies provides insights into the spread and impact of zoonotic diseases. For instance, the Ebola outbreak in West Africa highlighted the severe consequences of zoonotic diseases transmitted from wildlife, particularly bats and primates, to humans [81]. Likewise, the SARS outbreak in China was associated with zoonotic transmission from civet cats to humans. These cases emphasize the need for robust surveillance, research, and public health measures to manage and prevent zoonotic diseases. By understanding these outbreaks, public health officials can create effective strategies to limit the spread and impact of zoonoses.

6.3. Impact on wildlife and ecosystems

Infectious diseases and zoonotic agents significantly affect wildlife and their ecosystems, with implications for health, behavior, and ecological balance. This section explores these impacts in detail.

6.3.1. Wildlife health

Diseases in wildlife can have serious consequences, including high mortality rates, decreased reproductive success, and weakened immune responses [83–85]. For example, Chronic Wasting Disease (CWD) in deer causes severe neurological damage and often results in death, leading to declines in deer populations and altering predator-prey relationships [79]. Canine Distemper Virus (CDV) [86], which affects species like lions and wolves, causing respiratory and neurological problems, reducing population numbers and impacting species survival. Such outbreaks can significantly affect wildlife populations, altering their dynamics and ecosystem roles.

6.3.2. Ecosystem consequences

The health of wildlife is integral to ecosystem stability [87]. Disease-induced declines in key species can disrupt food webs and ecological interactions. For instance, a reduction in large herbivores due to disease can lead to unchecked vegetation growth, which impacts other herbivores and the entire food chain. Similarly, if apex predators succumb to diseases, prey populations may increase excessively, leading to imbalances in plant life and affecting other species. These disruptions can lead to lasting alterations in the ecosystem and a reduction in biodiversity.

6.3.3. Conservation challenges

Addressing the effects of diseases on wildlife and ecosystems poses significant challenges for conservation efforts [88]. Disease outbreaks can complicate conservation strategies, especially in areas where wildlife and domestic animals interact. Effective management requires comprehensive monitoring, research into disease patterns, and strategies to prevent disease transmission between wildlife and domestic animals. Additionally, tackling habitat destruction and climate change, which can worsen disease spread and impact wildlife health, is crucial for sustaining ecosystem health and resilience.

6.4. Prevention and management strategies

Preventing and managing infectious diseases in wildlife, and mitigating their effects on ecosystems, require a multifaceted approach. This section discusses essential strategies for disease prevention, monitoring, and management to safeguard both wildlife and human health.

6.4.1. Disease surveillance and monitoring

Effective management starts with comprehensive surveillance and monitoring [89]. This includes regularly tracking wildlife health and gathering data on disease prevalence and spread. Utilizing wildlife health monitoring programs and advanced technologies like remote sensing and molecular diagnostics can aid in early detection of outbreaks. Collaboration with local communities, researchers, and conservation groups can enhance the identification of emerging diseases and facilitate swift responses to potential threats.

6.4.2. Vaccination and treatment

Vaccination is a key preventive measure for controlling infectious diseases in wildlife [90]. Programs like rabies vaccination for wildlife can greatly reduce disease incidence and protect both animals and humans. While treatment options are often more complex to administer in wild populations, developing targeted therapeutic interventions is important. Tailoring vaccination and treatment strategies to specific species and disease patterns is crucial for their success.

6.4.3. Habitat management and biosecurity

Proper habitat management is essential for minimizing disease spread: ensuring healthy ecosystems and managing habitat disturbances can lessen stress on wildlife and reduce disease transmission risks. Implementing biosecurity measures is also vital in preventing the spread of disease. These measures involve limiting wildlife access to areas (where domestic animals are housed) and ensuring proper waste management to prevent contamination. Establishing buffer zones and protecting vital habitats can decrease wildlife-domestic animal interactions and further lower disease risks.

6.4.4. Public education and engagement

Educating the public and engaging communities are critical for effective disease management [91]. Raising awareness about zoonotic disease risks, safe handling practices, and the importance of reporting sick or deceased animals can improve monitoring and response efforts. Encouraging responsible wildlife and pet management, such as vaccinations and avoiding wildlife contact, helps prevent disease transmission. Cooperation between public health officials, conservationists, and local communities is vital for creating a unified approach to disease prevention.

6.4.5. Research and policy development

Research is fundamental for understanding disease dynamics, developing new prevention and treatment methods, and shaping policy. Supporting studies on wildlife diseases, their transmission, and ecological effects can lead to improved management strategies [92]. Crafting and implementing policies that address wildlife health, habitat conservation, and disease control are essential for reducing the impacts of infectious diseases on wildlife and ecosystems. Engaging policymakers and stakeholders in these efforts helps ensure the implementation of effective and long-lasting strategies.

6.5. Case studies: infectious agents and zoonotic diseases worldwide

6.5.1. Ebola virus outbreak in West Africa (2014-2016)

The Ebola outbreak in West Africa, affecting Guinea, Liberia, and Sierra Leone, provides a stark example of a zoonotic disease with significant human and wildlife impacts [93]. Transmitted from fruit bats and primates to humans through direct contact with infected bodily fluids, the outbreak led to over 11,000 deaths and caused severe economic and social disruptions. Conservation efforts during the outbreak included increased surveillance of wildlife populations and enhanced public health measures. The crisis highlighted the need for improved disease monitoring, rapid response capabilities, and international collaboration to manage zoonotic threats effectively.

6.5.2. Chronic Wasting Disease (CWD) in North America

Chronic Wasting Disease (CWD) affects deer, elk, and moose across the United States and Canada, causing severe neurological deterioration [94,95]. The disease, caused by prions, has resulted in substantial declines in affected populations and has raised concerns about its potential spread to other wildlife. Conservation strategies have focused on limiting deer movement, conducting extensive surveillance, and researching potential control measures. The ongoing challenge with CWD underscores the importance of continuous monitoring and adaptive management practices to protect wildlife populations and prevent further ecological disruptions.

6.5.3. Hantavirus Pulmonary Syndrome (HPS) in the Americas

Hantavirus Pulmonary Syndrome (HPS), transmitted to humans through contact with rodent excreta, has been reported in various parts of the Americas, particularly in rural and forested areas [96,97]. The disease causes severe respiratory illness and highlights the risk posed by rodent-borne pathogens. Management strategies involve public education to reduce exposure risks, improved rodent control measures, and increased surveillance of rodent populations. These efforts illustrate the need for integrated approaches to address zoonotic diseases that involve both public health and wildlife management components.

6.5.4. Avian influenza outbreaks in Asia and Europe

Avian influenza, commonly known as bird flu, caused by influenza A viruses, has impacted both poultry and wild bird populations, with significant outbreaks occurring in Asia and Europe. Highly pathogenic strains, such as H5N1, can infect humans and lead to severe illness. Control measures have included culling infected poultry, monitoring wild bird populations, and developing vaccines. These outbreaks emphasize the importance of biosecurity measures and surveillance in preventing disease spread, as well as the need for international cooperation to manage zoonotic risks effectively.

6.5.5. Leptospirosis in Latin America

Leptospirosis, a bacterial infection spread through contact with water contaminated by animal urine, is common in Latin America. The disease impacts both wildlife, such as rodents and humans, causing symptoms that can range from mild to severe. Outbreaks are often associated with heavy rainfall and flooding, which increases the risk of exposure. Outbreaks are often associated with heavy rains and flooding, which increases exposure risks. Conservation and public health efforts include improving sanitation, community education, and rodent control measures. This case underscores the importance of addressing environmental and social factors in managing zoonotic diseases and protecting public health.

6.5.6. Lessons learned

Global case studies of infectious agents and zoonotic diseases provide essential insights into improving disease management and conservation efforts [81,100–102]. Key takeaways emphasize the importance of early detection and swift action, as demonstrated by the Ebola outbreak in West Africa. This incident underscored the need for strong surveillance and rapid response systems to manage outbreaks effectively and reduce their impact. The approach to Chronic Wasting Disease (CWD) shows the effectiveness of integrated strategies, combining wildlife monitoring, habitat management, and research to address complex diseases like prion infections through collaborative efforts among conservationists, researchers, and policymakers. The response to Hantavirus Pulmonary Syndrome (HPS) and Leptospirosis demonstrates the importance of public education and community engagement, emphasizing how informing the public and involving communities in monitoring and control can enhance disease prevention and response. Avian influenza outbreaks underscore the importance of biosecurity measures and habitat management in controlling disease spread between wildlife, domestic animals, and humans. Finally, the global nature of zoonotic diseases like avian influenza and Ebola highlights the need for international cooperation, where sharing information, resources, and best practices across borders is crucial for effective disease management and preventing widespread outbreaks.

7. Toxicology of traditional hunting methods

Traditional hunting methods have long been integral to the subsistence and cultural practices of various communities. However, these methods can involve toxic substances and practices that pose risks to both hunters and the environment. This section examines the toxicological aspects of traditional hunting techniques, exploring the substances used, their effects, and strategies for mitigating associated risks.

7.1. Use of toxic substances in traditional hunting

7.1.1. Plant-derived toxins

Traditional hunting often employs plant-derived toxins for their potent effects [103–108]. For example, plants from the *Strychnos* genus produce strychnine, a highly toxic alkaloid used to poison arrows, causing severe muscle convulsions and death in prey, but also posing significant risks to humans and other non-target species if mishandled. Similarly, *Datura stramonium* (Jimsonweed) contains tropane alkaloids that induce hallucinations and severe poisoning symptoms, making it a dangerous choice for poisoning hunting tools [109]. These plant toxins, while effective, require careful handling due to their potential harm to both wildlife and humans.

7.1.2. Animal and mineral toxins

Animal-derived toxins are another component of traditional hunting practices [39,105,110]. The venom from Phyllobate frogs is used to coat darts, making them more lethal. However, this toxin is extremely potent and can be hazardous to humans and wildlife if accidentally contacted. Additionally, minerals like lead were historically used in bullets and shot, posing long-term environmental and health risks [111,112]. Lead contamination from spent ammunition can poison wildlife that ingests it and has broader ecological impacts, highlighting the need for safer alternatives in hunting practices. Other substances are used as poisonous bait to kill wild games [106].

7.2. Toxicological effects on hunters and communities

Using toxic substances in traditional hunting methods can have severe toxicological consequences for hunters and their communities, manifesting as both immediate and long-term health issues [103,113,114].

7.2.1. Acute toxicity

Acute toxicity arises when hunters are exposed to high levels of toxins; either through direct contact or accidental ingestion. For example, strychnine, used on poisoned arrows, can cause intense convulsions, breathing difficulties, and even death. Similarly, toxins from *Datura stramonium* can induce severe symptoms such as hallucinations and delirium, posing serious health risks. These immediate effects necessitate swift medical treatment to prevent severe outcomes or fatalities, underscoring the hazards associated with handling and applying toxic substances in hunting.

7.2.2. Chronic exposure

Chronic exposure occurs when individuals repeatedly come into contact with or consume games contaminated with toxins, leading to long-term health issues. For instance, lead poisoning from eating game shots with lead ammunition can result in significant neurological and developmental problems, especially in vulnerable groups like children and pregnant women. Prolonged exposure to plant toxins, even in smaller quantities, can cause ongoing health issues affecting various body systems. These chronic effects can strain healthcare resources and affect community health, illustrating the broader impact of persistent exposure to hunting toxins.

8. Evaluating and managing risks

Risk assessment and management are crucial for mitigating the dangers associated with traditional hunting practices, toxic substances, and environmental contaminants. This section explores the processes and strategies used to evaluate and address risks to both human health and the environment.

8.1. Risk assessment

8.1.1. Identifying hazards

The first step in the risk assessment is to identify potential hazards associated with traditional hunting practices and toxic substances [115]. This involves recognizing dangerous plants such as *Strychnos* species, which contain the potent toxin strychnine, and *Datura stramonium*, known for its hallucinogenic tropane alkaloids. It also includes identifying animal-derived toxins, such as those from Phyllobate frogs whose venom is used in hunting darts, and mineral toxins like lead found in ammunition. Understanding these hazards is essential for gauging the associated risks to human health and the environment.

8.1.2. Analyzing exposure

Analyzing exposure involves investigating how individuals and communities come into contact with these hazards. This involves examining how toxic substances are applied to hunting tools, the amounts and frequencies of their use, and the safety measures implemented by hunters.. It also covers how toxins might enter the body through consuming contaminated game, touching contaminated surfaces, or inhaling toxic fumes. This analysis is crucial for assessing the level of risk posed by each hazard.

8.1.3. Evaluating health effects

Evaluating health effects focuses on the potential impacts of these hazards on human health and the environment; this involves examining immediate effects such as poisoning symptoms, convulsions, and respiratory issues resulting from high levels of exposure. It also considers chronic effects from repeated or lower-level exposure, such as neurological damage and developmental issues. Additionally, it evaluates environmental impacts, including the poisoning of non-target wildlife, disruption of food chains, and contamination of soil and water sources.

8.1.4. Risk characterization

Risk characterization combines information from hazard identification, exposure analysis, and health effects evaluation to provide an overall risk assessment. This involves estimating the likelihood and severity of adverse effects and prioritizing risks based on their potential impact. It also involves identifying uncertainties and gaps in data that could influence the accuracy of the risk assessment. This comprehensive approach helps in effectively allocating resources and devising targeted strategies to address the most pressing risks.

8.2. Risk management

Risk management focuses on creating and applying strategies to reduce the dangers associated with traditional hunting practices and toxic substances [24,116–119]. This involves a series of measures designed to lessen or eliminate risks to human health and the environment.

8.2.1. Implementing safety protocols

To minimize risks from toxic substances, it is essential to establish and enforce safety protocols. This includes creating detailed guidelines for safe handling, application, and disposal of toxins. Providing hunters with training on safe practices and the proper use of personal protective equipment (PPE) is crucial to prevent accidents and reduce exposure to harmful substances. Adhering to these safety protocols helps avoid poisoning and other related issues.

8.2.2. Creating alternative methods

Exploring and promoting safer alternatives to traditional toxic substances is a key component of risk management [120–122]. This involves researching and adopting non-toxic options for hunting tools, such as alternative coatings for arrows or darts that do not pose significant health or environmental risks [123]. Additionally, encouraging the use of alternative hunting techniques that do not rely on harmful substances can further decrease risk [124,125]. Innovations in safer methods can help maintain traditional practices while reducing associated dangers.

8.2.3. Monitoring and surveillance

Monitoring and surveillance are vital for assessing the effectiveness of risk management strategies and identifying potential problems [126]. This involves tracking health outcomes related to toxic exposure, measuring environmental contamination levels, and ensuring adherence to safety guidelines. Effective surveillance helps detect new risks and trends, allowing for timely adjustments to management practices. Regular reviews ensure that risk management efforts remain effective and up-to-date.

8.2.4. Public education and awareness

Increasing public awareness and offering education are essential for reducing risks associated with toxic substances in hunting. Informing hunters and communities about the dangers of toxins, safe handling procedures, and the importance of protective equipment can help prevent health issues and accidents. Awareness campaigns also support the adoption of safer hunting practices and alternatives, which contributes to overall risk reduction.

8.2.5. Regulation and policy development

Developing and enforcing regulations to control the use of hazardous substances is an important aspect of risk management. This includes setting rules that restrict or ban certain toxic substances, establishing safety standards, and imposing penalties for non-compliance. Effective regulation helps control the use of hazardous materials and ensures that safety protocols are adhered to. Collaboration with policymakers, researchers, and local communities is essential for creating and enforcing these regulations.

8.3. Case studies and lessons learned

Analyzing case studies offers crucial insights into the application of risk assessment and management strategies, revealing valuable lessons for enhancing safety and effectiveness.

8.3.1. Case study 1: lead poisoning in Wildlife

A significant case study is the management of lead poisoning among wildlife, particularly in areas with high use of lead ammunition [127]. Lead poisoning has caused serious health issues, including neurological damage and death, in various animal species [111]. In response, measures of restricting lead shots (in particular regions), promoting non-toxic alternatives, and initiating public awareness campaigns have been taken. These initiatives highlight the significance of adopting safer materials and underscore the necessity for ongoing evaluation to assess the effectiveness of these measures.

8.3.2. Case study 2: reducing exposure to plant toxins

Another key case study focuses on minimizing exposure to toxic plants used in traditional hunting, such as *Datura stramonium*. Efforts have focused on improving hunting practices and raising awareness about the dangers of these plants. Educational programs that teach hunters how to identify and avoid toxic plants have proven effective in reducing cases of poisoning. This case underscores the importance of education and preventive measures in managing health risks associated with toxic substances.

8.3.3. Case study 3: management of animal-derived toxins

A third case study explores the management of animal-derived toxins, such as those from *Phyllobate* frogs used in hunting darts. Research into non-toxic alternatives and changes in hunting practices have helped mitigate the risks associated with these potent toxins. This case demonstrates the value of investing in safer alternatives and educating hunters about the proper handling of toxic materials.

These case studies highlight the success of various risk management strategies, including banning hazardous substances, adopting safer alternatives, and providing targeted education. They also emphasize the need for ongoing evaluation and adaptation to address new risks and ensure the protection of both human health and the environment.

9. Conclusion

Addressing the challenges posed by traditional hunting practices, toxic substances, and environmental contaminants requires a thorough approach to risk assessment and management. By recognizing the specific toxins, assessing their effects on health and wildlife, and studying their mechanisms of toxicity, we can develop effective strategies to mitigate these risks.

Risk assessment entails identifying hazards, measuring exposure levels, and assessing health impacts to determine the magnitude of potential risks. This information is crucial for creating effective risk management strategies, which include establishing safety protocols, exploring safer alternatives, and enhancing public awareness. Regular monitoring and regulation are crucial in managing and minimizing the risks associated with traditional hunting and toxic substances.

Case studies offer important insights into the success of different risk management practices and highlight key lessons from actual experiences. These cases demonstrate the benefits of safer practices, the need for research into alternative solutions, and the importance of education and awareness in reducing risks.

In summary, the aim is to conduct traditional hunting methods safely while protecting human health and the environment. By combining risk assessment with proactive management strategies and learning from past case studies, we can foster safer and more sustainable practices that benefit both communities and ecosystems.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Chardonnet Ph, Des Clers B, Fisher JR, Gerhold R, Jori F, Lamarque F. The value of wildlife: -EN- -FR- -ES-. Rev Sci Tech OIE. 2002; 21(1):15-51.

[2] Roselli C, Desideri D, Meli MA, Fagiolino I, Feduzi L. Essential and toxic elements in meat of wild birds. J Toxicol Environ Health A. 2016; 79(21):1008-1014.

[3] Desideri D, Meli MA, Cantaluppi C, Ceccotto F, Roselli C, Feduzi L. Essential and toxic elements in meat of wild and bred animals. Toxicol Environ Chem. 2012; 94(10):1995-2005.

[4] Nkosi DV, Bekker JL, Hoffman LC. Toxic Metals in Wild Ungulates and Domestic Meat Animals Slaughtered for Food Purposes: A Systemic Review. Foods. 2021; 10(11):2853.

[5] Rahman MdT, Sobur MdA, Islam MdS, Ievy S, Hossain MdJ, El Zowalaty ME, et al. Zoonotic Diseases: Etiology, Impact, and Control. Microorganisms. 2020; 8(9):1405.

[6] Milgroom MG. Emerging Infectious Diseases. In: Milgroom MG, éditeur. Biology of Infectious Disease: From Molecules to Ecosystems. Cham: Springer International Publishing. 2023:285-303.

[7] Mackenzie JS, Jeggo M, Daszak P, Richt JA, éditeurs. One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases: The Concept and Examples of a One Health Approach. Berlin, Heidelberg: Springer Berlin Heidelberg. 2013; 366:238p.

[8] Robinson JG, Bennett EL, éditeurs. Hunting for sustainability in tropical forests. New York, NY: Columbia Univ. Press. 2000: 582 p.

[9] Jama'a NA, Jamilu H, Misau AB, Buhari S, Sani A. Game meats, a heart-healthy choice it's contributions in reducing animal protein malnutrition: review. Niger J Anim Prod. 2022; 1725-8.

[10] Hoffman LC. The yield and nutritional value of meat from African ungulates, camelidae, rodents, ratites and reptiles. Meat Sci. 2008; 80(1):94-100.

[11] Cawthorn DM. What is the role and contribution of meat from wildlife in providing high quality protein for consumption? Anim Front. 2012; 2:40-53.

[12] Kehinde AS, Adelakun KM, Halidu SK, Bobadoye AO, Babatunde TO, Fadimu BO. Nutrient qualities of selected bushmeat in new bussa and its environs, nigeria. ejesm. 2020; 13(5):579-87.

[13] Nasi R, Fa J, van Vliet N, Coad L, Pinedo-Vasquez M, Swamy V, et al. Wild Meat. The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). 2021: 65.

[14] Nunes AV, Peres CA, Constantino P de AL, Fischer E, Nielsen MR. Wild meat consumption in tropical forests spares a significant carbon footprint from the livestock production sector. Sci Rep. 2021; 11(1):19001.

[15] Krausman PR, Cain JW. Wildlife Management and Conservation: Contemporary Principles and Practices. JHU Press. 2022. 468 p.

[16] Tumelty L, Fa JE, Coad L, Friant S, Mbane J, Kamogne CT, et al. A systematic mapping review of links between handling wild meat and zoonotic diseases. One Health. 2023; 17:100637.

[17] van Vliet N, Muhindo J, Nyumu J, Enns C, Massé F, Bersaglio B, et al. Understanding Factors that Shape Exposure to Zoonotic and Food-Borne Diseases Across Wild Meat Trade Chains. Hum Ecol. 2022; 50(6):983-95.

[18] Ferreira MN, Elliott W, Kroner RG, Prist PR, Valdujo P, Vale MM. Drivers and causes of zoonotic diseases: An overview. PARKS. 2021; 2(27):15-24.

[19] Ciobanu MM, Munteanu M, Postolache AN. Toxic heavy metals content in wild boar and venison meat: a brief review. Sci Pap Ser Anim Sci. 2020; LXIII(1):435-41.

[20] Berny P. Pesticides and the intoxication of wild animals. J Vet Pharmacol Ther. 2007; 30(2):93-100.

[21] Rohani MF. Pesticides toxicity in fish: Histopathological and hemato-biochemical aspects – A review. Emerg Contam. 2023; 9(3):100234.

[22] Uryu Y, Malm O, Thornton I, Payne I, Cleary D. Mercury Contamination of Fish and Its Implications for Other Wildlife of the Tapajós Basin, Brazilian Amazon. Conserv Biol. 2001; 15(2):438-46.

[23] Ampofo HJ, Emikpe BO, Asenso TN, Asare DA, Yeboah R, Jarikre TA, et al. Hunting practices and heavy metals concentrations in fresh and smoked wildmeats in Kumasi, Ghana. J Res For Wildl Environ. 2017;9(3):43-9.

[24] Arnemo JM, Fuchs B, Sonne C, Stokke S. Hunting with Lead Ammunition: A One Health Perspective. In: Tryland M, éditeur. Arctic One Health: Challenges for Northern Animals and People. Cham: Springer International Publishing; 2022:439-68.

[25] Wren CD. A review of metal accumulation and toxicity in wild mammals: I. Mercury. Environ Res. 1986; 40(1):210-44.

[26] Wren CD. A review of metal accumulation and toxicity in wild mammals: I. Mercury. Environ Res. 1986; 40(1):210-44.

[27] Friend M. Chemical Toxins (Field Manual of Wildlife Diseases). Zoonotics Wildl Dis Publ. 1999; 284-353.

[28] Stegelmeier BL, Davis TZ. Poisonous Plants. In: Haschek WM, Rousseaux CG, Wallig MA, Bolon B, Heinz-taheny KM, Rudmann DG, et al., éditeurs. Haschek and Rousseaux's Handbook of Toxicologic Pathology (Fourth Edition). Academic Press. 2023:489-546.

[29] Nwaji AR, Arieri O, Anyang AS, Nguedia K, Abiade EB, Forcados GE, et al. Natural toxins and One Health: a review. Sci One Health. 2022; 1:100013.

[30] Adamski Z, Bufo SA, Milella L, Scrano L. Identification and functional characterization of plant toxins. Vol. 13, Toxins. MDPI. 2021:228.

[31] Breinlinger S, Phillips TJ, Haram BN, Mareš J, Martínez Yerena JA, Hrouzek P, et al. Hunting the eagle killer: A cyanobacterial neurotoxin causes vacuolar myelinopathy. Science. 2021; 371(6536): eaax9050.

[32] Ndubuisi ND, Chidiebere ACU. Cyanide in Cassava: A Review. 2018; 2018(01):1-10.

[33] Fung F, Clark R. Health Effects of Mycotoxins: A Toxicological Overview. J Toxicol Clin Toxicol. 2004; 42:217-34.

[34] Weidenbörner M. Natural Mycotoxin Contamination in Humans and Animals. Cham: Springer International Publishing. 2015: 355 p.

[35] Peraica M, Radić B, Lucić A, Pavlović M. Toxic effects of mycotoxins in humans. Bull World Health Organ. 1999; 77(9):754.

[36] Hussein HS, Brasel JM. Toxicity, metabolism, and impact of mycotoxins on humans and animals. Toxicology. 2001; 167(2):101-134.

[37] Berry LJ, Mergenhagen SE. Bacterial Toxins. CRC Crit Rev Toxicol. 1977; 5(3):239-318.

[38] Jurėnas D, Fraikin N, Goormaghtigh F, Van Melderen L. Biology and evolution of bacterial toxin–antitoxin systems. Nat Rev Microbiol. 2022;20(6):335-50.

[39] Rahman H, Mahmoud B, Othman H. A Review of History, Definition, Classification, Source, Transmission, and Pathogenesis of Salmonella: A Model for Human Infection. J Zankoy Sulaimani - Part A. 2018; 20:11-20.

[40] Habermehl GG. Venomous Animals and Their Toxins. Berlin, Heidelberg: Springer Berlin Heidelberg; 1981. 204 p.

[41] Bolon B, Heinz-Taheny K, Yeung KA, Oguni J, Erickson TB, Chai PR, et al. Animal Toxins. In: Haschek and Rousseaux's Handbook of Toxicologic Pathology. Elsevier; 2023:547-628.

[42] Singer M. Venom. Millbrook Press. 2020. 99 p.

[43] Rajput A, Sharma R, Bharti R. Pharmacological activities and toxicities of alkaloids on human health. Mater Today Proc. 2022; 48:1407-15.

[44] Bernanke J, Köhler HR. The Impact of Environmental Chemicals on Wildlife Vertebrates. Rev Environ Contam Toxicol. 2009; 198:1-47.

[45] Milburn MP. Indigenous Nutrition: using traditional food knowledge to solve contemporary health problems. Am Indian Q. 2004; 28(3/4):411-34.

[46] Drašković V, Glišić M, Cvetković R, Teodorović R, Janković L, Đorđević M. Anticoagulant rodenticides in game meat: a risk to human health. Sci J Meat Technol. 2023; 64(2):194-8.

[47] Vigneri R, Malandrino P, Gianì F, Russo M, Vigneri P. Heavy metals in the volcanic environment and thyroid cancer. Mol Cell Endocrinol. 2017; 457:73-80.

[48] Wuana RA, Okieimen FE. Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. Int Sch Res Not. 2011; 2011(1):402647.

[49] Günthardt BF, Hollender J, Hungerbühler K, Scheringer M, Bucheli TD. Comprehensive Toxic Plants–Phytotoxins Database and Its Application in Assessing Aquatic Micropollution Potential. J Agric Food Chem. 2018; 66(29):7577-88.

[50] Asuku AO, Ayinla MT, Ajibare AJ, Adeyemo MB, Adeyemo RO. Heavy Metals and Emerging Contaminants. In: Emerging Contaminants in Food and Food Products. CRC Press. 2024; 236-50.

[51] Ramírez-Malule H, Quiñones-Murillo DH, Manotas-Duque D. Emerging contaminants as global environmental hazards. A bibliometric analysis. Emerg Contam. 2020; 6:179-93.

[52] Gupta T, Agarwal AK, Agarwal RA, Labhsetwar NK, éditeurs. Environmental Contaminants: Measurement, Modelling and Control. Singapore: Springer Singapore; 2018: 441 p.

[53] Noyes PD, McElwee MK, Miller HD, Clark BW, Van Tiem LA, Walcott KC, et al. The toxicology of climate change: environmental contaminants in a warming world. Environ Int. 2009; 35(6):971-86.

[54] Morin-Crini N, Lichtfouse E, Liu G, Balaram V, Ribeiro ARL, Lu Z, et al. Worldwide cases of water pollution by emerging contaminants: a review. Environ Chem Lett. Août. 2022;20(4):2311-38.

[55] Wu Q, Leung JYS, Geng X, Chen S, Huang X, Li H, et al. Heavy metal contamination of soil and water in the vicinity of an abandoned e-waste recycling site: Implications for dissemination of heavy metals. Sci Total Environ. 2015; 506-507:217-25.

[56] Akhtar ABT, Naseem S, Yasar A, Naseem Z. Persistent Organic Pollutants (POPs): Sources, Types, Impacts, and Their Remediation. In: Prasad R, éditeur. Environmental Pollution and Remediation. Singapore: Springer Singapore. 2021: 213-46.

[57] Lal R. Soils and sustainable agriculture. A review. Agron Sustain Dev. 2008; 28(1):57-64.

[58] Reed MS. Stakeholder participation for environmental management: A literature review. Biol Conserv. 2008; 141(10):2417-31.

[59] Xue X, Hong H, Zhang L, Xu X, Shen SS. Developing public environmental education: Improving community-based environmental management. Aquat Ecosyst Health Manag. 2006; 9(1):105-10.

[60] Eto K. Minamata Disease. Neuropathology. 2000; 20(s1):14-9.

[61] Pauli BJ. The Flint water crisis. WIREs Water. 2020;7(3):e1420.

[62] Takaoka S, Fujino T, Kawakami Y. Health Hazard Still Emerged Even After 1968, When Chisso Company Stopped Mercury Drainage. Epidemiology. 2011; 22(1):S298.

[63] Mishra PK, Samarth RM, Pathak N, Jain SK, Banerjee S, Maudar KK. Bhopal gas tragedy: review of clinical and experimental findings after 25 years. Int J Occup Med Environ Health. 2009; 22(3):193.

[64] Ipe M. Bhopal Gas Tragedy: Lessons for corporate social responsibility. Soc Responsib J. 2005; 1(3/4):122-41.

[65] Mazur A. A hazardous inquiry: the Rashomon effect at Love Canal. Harvard University Press. 1998: 272 p.

[66] Torres JPM, Lailson-Brito J, Saldanha GC, Dorneles P, Silva CEA, Malm O, et al. Persistent toxic substances in the Brazilian Amazon: contamination of man and the environment. J Braz Chem Soc. 2009; 20:1175-9.

[67] Yablokov AV. Chernobyl's radioactive impact on fauna. Chernobyl. 2010; 255.

[68] Mousseau TA, Møller AP. Landscape portrait: A look at the impacts of radioactive contaminants on Chernobyl's wildlife. Bull At Sci. 2011; 67(2):38-46.

[69] Garland T, éditeur. Toxic plants and other natural toxicants. Repr. Wallingford: CABI Publ; 1999. 585 p.

[70] Stegelmeier BL, Field R, Panter KE, Hall JO, Welch KD, Pfister JA, et al. Selected poisonous plants affecting animal and human health. In: Haschek and Rousseaux's Handbook of Toxicologic Pathology. Elsevier. 2013: 259-314.

[71] Dauncey EA, Larsson S. Plants that kill: A natural history of the world's most poisonous plants. Princeton University Press. 2018:224.

[72] Cooper-Driver GA. Chemical substances in plants toxic to animals. In: Handbook of Naturally Occurring Food Toxicants. CRC Press. 2018:213-40.

[73] Botelho AFM, Pierezan F, Soto-Blanco B, Melo MM. A review of cardiac glycosides: Structure, toxicokinetics, clinical signs, diagnosis and antineoplastic potential. Toxicon. 2019; 158:63-8.

[74] Fuchs J, Rauber-Lüthy C, Kupferschmidt H, Kupper J, Kullak-Ublick GA, Ceschi A. Acute plant poisoning: Analysis of clinical features and circumstances of exposure. Clin Toxicol. 2011; 49(7):671-80.

[75] ason CT, Milne L, Potts M, Morriss G, Wright GRG, Sutherland ORW. Secondary and Tertiary Poisoning Risks Associated with Brodifacoum. N Z J Ecol. 1999; 23(2):219-24.

[76] Ellenhorn MJ, Barceloux DG. Diagnosis and treatment of human poisoning. Med Toxicol. 1997; 609-10.

[77] Ng WY, Hung LY, Lam YH, Chan SS, Pang KS, Chong YK, et al. Poisoning by toxic plants in Hong Kong: a 15-year review. Hong Kong Med J. 2019; 25(2):102.

[78] Mackenzie JS, Jeggo M, Daszak P, Richt JA. One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases: Food Safety and Security, and International and National Plans for Implementation of One Health Activities. Berlin, Heidelberg: Springer Berlin Heidelberg. 2013;366p

[79] Cleaveland S, Laurenson K, Mlengeya T. Impacts of Wildlife Infections on Human and Livestock Health with Special Reference to Tanzania: Implications for Protected Area Management. In: Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health. Gland, Switzerland, IUCN. 2005:147-51.

[80] EFSA Panel on Biological Hazards (BIOHAZ), Ricci A, Allende A, Bolton D, Chemaly M, Davies R, et al. Chronic wasting disease (CWD) in cervids. EFSA J. 2017; 15(1).

[81] Kruse H, Kirkemo AM, Handeland K. Wildlife as Source of Zoonotic Infections. Emerg Infect Dis. déc 2004; 10(12):2067-72.

[82] Ezenwa VO, Prieur-Richard AH, Roche B, Bailly X, Becquart P, García-Peña GE, et al. Interdisciplinarity and Infectious Diseases: An Ebola Case Study. Rall GF, éditeur. PLOS Pathog. 2015; 11(8):e1004992.

[83] Lytras S, Xia W, Hughes J, Jiang X, Robertson DL. The animal origin of SARS-CoV-2. Science. 2021; 373(6558):968-70.

[84] Acevedo-Whitehouse K, Duffus ALJ. Effects of environmental change on wildlife health. Philos Trans R Soc B Biol Sci. 2009; 364(1534):3429-38.

[85] Scott ME. The Impact of Infection and Disease on Animal Populations: Implications for Conservation Biology. Conserv Biol. 1988; 2(1):40-56.

[86] Tompkins DM, Dunn AM, Smith MJ, and Telfer S. Wildlife diseases: from individuals to ecosystems: Ecology of wildlife diseases. J Anim Ecol. 2011; 80(1):19-38.

[87] Hopper M. Montana Chronic Wasting Disease Management Plan. Montana fish, wild life and parks; 2020.

[88] Deem SL, Karesh WB, Weisman W. Putting Theory into Practice: Wildlife Health in Conservation. Conserv Biol. 2001; 15(5):1224-33.

[89] Daszak P, Cunningham A, Hyatt A. Emerging Infectious Diseases of Wildlife-- Threats to Biodiversity and Human Health. Science. 1 févr 2000; 287:443-9.

[90] Artois M, Bengis R, Delahay RJ, Duchêne MJ, Duff JP, Ferroglio E, et al. Wildlife Disease Surveillance and Monitoring. In: Delahay RJ, Smith GC, Hutchings MR, éditeurs. Management of Disease in Wild Mammals. Tokyo: Springer Japan. 2009:187-213.

[91] Newton EJ, Pond BA, Tinline RR, Middel K, Bélanger D, Rees EE. Differential impacts of vaccination on wildlife disease spread during epizootic and enzootic phases. J Appl Ecol. 2019; 56(3):526-36.

[92] Newton EJ, Pond BA, Tinline RR, Middel K, Bélanger D, Rees EE. Differential impacts of vaccination on wildlife disease spread during epizootic and enzootic phases. J Appl Ecol. 2019; 56(3):526-36.

[93] Cross PC, Drewe J, Patrek V, Pearce G, Samuel MD, Delahay RJ. Wildlife Population Structure and Parasite Transmission: Implications for Disease Management. In: Delahay RJ, Smith GC, Hutchings MR, éditors. Management of Disease in Wild Mammals. Tokyo: Springer Japan. 2009:9-29.

[94] Gatherer D. The 2014 Ebola virus disease outbreak in West Africa. J Gen Virol. 2014; 95(8):1619-24.

[95] Gilch S, Chitoor N, Taguchi Y, Stuart M, Jewell JE, Schätzl HM. Chronic Wasting Disease. In: Tatzelt J, éditeur. Prion Proteins. Berlin, Heidelberg: Springer Berlin Heidelberg. 2011:51-77.

[96] Mysterud A, Edmunds DR. A review of chronic wasting disease in North America with implications for Europe. Eur J Wildl Res. 2019; 65(2):26.

[97] MacNeil A, Nichol ST, Spiropoulou CF. Hantavirus pulmonary syndrome. Virus Res. 2011; 162(1):138-47.

[98] Peters CJ. Hantavirus Pulmonary Syndrome in the Americas. In: Scheld WM, Craig WA, Hughes JM, éditeurs. Emerging Infections 2. Washington, DC, USA: ASM Press. 2014:17-64.

[99] Alexander DJ. An overview of the epidemiology of avian influenza. Vaccine. 2007; 25(30):5637-44.

[100] Petrakovsky J, Bianchi A, Fisun H, Nájera-Aguilar P, Pereira M. Animal Leptospirosis in Latin America and the Caribbean Countries: Reported Outbreaks and Literature Review (2002–2014). Int J Environ Res Public Health. 2014; 11(10):10770-89.

[101] Petrakovsky J, Bianchi A, Fisun H, Nájera-Aguilar P, Pereira M. Animal Leptospirosis in Latin America and the Caribbean Countries: Reported Outbreaks and Literature Review (2002–2014). Int J Environ Res Public Health. 2014; 11(10):10770-89.

[102] Haley N, Donner R, Merrett K, Miller M, Senior K. Selective Breeding for Disease-Resistant PRNP Variants to Manage Chronic Wasting Disease in Farmed Whitetail Deer. Genes. 2021; 12(9):1396.

[103] Park C. Lessons learned from the World Health Organization's late initial response to the 2014-Ebola outbreak in West Africa. J Public Health Afr. 2022; 13(1):1254.

[104] Anywar G. Historical Use of Toxic Plants. In: Mtewa AG, Egbuna C, Rao GMN, éditeurs. Poisonous Plants and Phytochemicals in Drug Discovery. Wiley. 2020:1-17.

[105] Wadley L, Trower G, Backwell L, d'Errico F. Traditional Glue, Adhesive and Poison Used for Composite Weapons by Ju/'hoan San in Nyae Nyae, Namibia. Implications for the Evolution of Hunting Equipment in Prehistory. Petraglia MD, éditeur. PLOS ONE. 2015; 10(10):e0140269.

[106] Chaboo CS, Hitchcock RK, Bradfield J, Wadley L. Beetle and Plant Arrow Poisons of the San People of Southern Africa. In: Toxicology in Antiquity. Elsevier; 2019:11-71.

[107] Banasik M, Stedeford T. Plants, Poisonous (Humans). In: Encyclopedia of Toxicology. Elsevier: 2014:970-8.

[108] Gupta PK. Introduction and historical background. In: Gupta PK, éditor. Fundamentals of Toxicology. Academic Press. 2016:3-7.

[109] Neuwinger HD. Alkaloids in Arrow Poisons. In: Roberts MF, Wink M, éditeurs. Alkaloids. Boston, MA: Springer US. 1998:45-84.

[110] Albuquerque UP, Melo JG, Medeiros MF, Menezes IR, Moura GJ, Asfora El-Deir AC, et al. Natural Products from Ethnodirected Studies: Revisiting the Ethnobiology of the Zombie Poison. Evid Based Complement Alternat Med. 2012; 2012:1-19.

[111] Fisher IJ, Pain DJ, Thomas VG. A review of lead poisoning from ammunition sources in terrestrial birds. Biol Conserv. 2006; 131(3):421-32.

[112] Nkosi DV, Bekker JL, Hoffman LC. Toxic Metals in Meat Contributed by Helicopter and Rifle Thoracic Killing of Game Meat Animals. Appl Sci. 2022; 12(16):8095.

[113] Verbrugge L, Wenzel S, Berner J, Matz A. Human exposure to lead from ammunition in the circumpolar north. In: The Peregrine Fund, Boise, Idaho. 2009:1-11.

[114] Pain DJ, Cromie RL, Newth J, Brown MJ, Crutcher E, Hardman P, et al. Potential Hazard to Human Health from Exposure to Fragments of Lead Bullets and Shot in the Tissues of Game Animals. Iwaniuk A, éditeur. PLoS ONE. 2010; 5(4):e10315.

[115] Arquette M, Cole M, Cook K, LaFrance B, Peters M, Ransom J, et al. Holistic risk-based environmental decision making: a Native perspective. Environ Health Perspect. 2002; 110(suppl 2):259-64.

[116] Thomas VG, Pain DJ, Kanstrup N, Cromie R. Increasing the Awareness of Health Risks from Lead-Contaminated Game Meat Among International and National Human Health Organizations. Eur J Environ Public Health. 2022; 6(2):em0110.

[117] Moriarity RJ, Tsuji LJS, Liberda EN. A probabilistic hazard and risk assessment of exposure to metals and organohalogens associated with a traditional diet in the Indigenous communities of Eeyou Istchee (northern Quebec, Canada). Environ Sci Pollut Res. 2023; 30(6):14304-17.

[118] WHO. Guidelines on the prevention of toxic exposures: education and public awareness activities. 2004: 99.

[119] Chashchin V, Kovshov AA, Thomassen Y, Sorokina T, Gorbanev SA, Morgunov B, et al. Health Risk Modifiers of Exposure to Persistent Pollutants among Indigenous Peoples of Chukotka. Int J Environ Res Public Health. 2019; 17(1):128.

[120] Thomas VG, Guitart R. Evaluating Non-toxic Substitutes for Lead Shot and Fishing Weights-Criteria and Regulations. Envtl Pol L. 2003; 33:150.

[121] Thomas VG, Guitart R. Evaluating Non-toxic Substitutes for Lead Shot and Fishing Weights-Criteria and Regulations. Envtl Pol L. 2003; 33:150.

[122] Cromie R, Newth J, and Strong E. Transitioning to non-toxic ammunition: Making change happen. Ambio. 2019; 48(9):1079-96.

[123] Lowden R, Kelly R. Application of powder metallurgy techniques for the development of non-toxic ammunition. Final CRADA report. Oak Ridge Y-12 Plant (Y-12), Oak Ridge, TN (United States). 1997: 27p.

[124] Mondain-Monval JY, Defos Du Rau P, Guillemain M, Olivier A. Switch to non-toxic shot in the Camargue, France: effect on waterbird contamination and hunter effectiveness. Eur J Wildl Res. 2015; 61(2):271-83.

[125] Thomas VG. Chemical compositional standards for non-lead hunting ammunition and fishing weights. Ambio. 2019;48(9):1072-8

[126] Abelsohn A, Gibson BL, Sanborn MD, Weir E. Identifying and managing adverse environmental health effects: 5. Persistent organic pollutants. Persistent Org Pollut. 2002; 166(12):1549-54.

[127] Pain DJ, Mateo R, Green RE. Effects of lead from ammunition on birds and other wildlife: A review and update. Ambio. 2019;48(9):935-53.