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REVIEW ARTICLE

# Endocrine Disruption by Heavy Metals: An In-Depth Analytical Review

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## ABSTRACT

Lead, mercury, cadmium, and arsenic are well-known heavy metals that are potentially toxic and continue to impact the environment. These compounds can interfere with the endocrine system, causing drastic effects on individual health. Endocrine disruptors can cause hormonal dysfunction at the site of production, release, transport, metabolism, binding, action, or elimination leading to reproductive, developmental, neurological, and immune disorders in humans and wildlife.

For example, cadmium imitates estrogen and binds to estrogen receptors, triggering pathological hormonal responses. Lead exposure has been linked to alterations in the hypothalamic-pituitary-adrenal axis, affecting stress hormone balance and cognitive performance. Mercury disrupts thyroid hormone metabolism, impairing thyroid function and child development.

Heavy metals also harm the immune system. Lead and cadmium weaken both general and specific immune defences, increase susceptibility to infections, alter cytokine signalling, and raise the risk of autoimmune diseases. Mercury is associated with weakened immune responses and abnormal antibody production. These changes compromise the body's ability to protect itself and elevate overall health risks.

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These metals accumulate in the food chain, posing greater threats to both human health and the ecological environment. Studying the molecular mechanisms of endocrine disruption by heavy metals is crucial for developing effective policies and protective strategies. Government and health guidelines should focus on minimizing environmental contamination, improving diagnostic tools, and raising public awareness. Coordinated efforts from governments, academia, industry, and communities are essential to safeguard present and future generations and promote a healthier world.

**KEYWORDS**

• Endocrine Disruption • Heavy Metals • Environmental Pollutants • Lead • Mercury • Cadmium • Arsenic

**Key Messages:** Heavy metals like lead, mercury, cadmium, and arsenic disrupt endocrine and immune systems, causing serious health issues. Their accumulation in the environment and food chain demands coordinated global action to reduce exposure and protect human and ecological health.

## INTRODUCTION

Endocrine Disruption is any kind of disturbance caused to the normal functioning of the endocrine system, which regulates the bodies' hormone synthesis. Hormones play diverse role in the homeostasis of the body, these have major impact on the development, growth, metabolism, reproduction, and overall balance. If the functioning of endocrine system is disturbed or hindered due to any reason there may be detrimental effects on one's health. Endocrine-disrupting chemicals (EDCs) are found to be associated with, for instance, to tumors associated with hormones, abnormal development, and many reproductive issues[1]. It is very important to understand endocrine disruption as it impacts both individual health and the population's overall well-being. Heavy metals are the group of elements that have high atomic weight and high relative density. They include Lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As), Iron (Fe), Zinc (Zn) and others. While some heavy metals, such as iron, zinc, and copper, are essential in low concentration for biological processes, but can cause significant risk to the health. Then there are various heavy metals like Lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As) which serve no biological purpose and cause damage to the health even at low concentration. These pollutants are released into the environment via mining, industrial activities, waste disposal, and agriculture.

They survive in soil, water, and air after being released. Heavy metal exposure occurs when food, water, and air are tainted. It is noteworthy that heavy metals can build up in tissues and affect health in a long-term way. Over time, heavy metals build up in living things. Even at low exposure levels, poisoning can result from prolonged exposure. For instance, long-term lead exposure has an impact on cardiovascular health, cognitive function, and the neurological system.[2] Certain heavy metals disrupt hormone signaling pathways, which is how they function as EDCs. For example, cadmium interferes with thyroid function and estrogen receptors, which impacts bone metabolism and reproductive health.[3] Entire communities are impacted by heavy metals.

Exposure to mercury from tainted fish impacts ecosystems and food chains in addition to individuals. The impact of heavy metals is evaluated to inform rules and regulations. For the sake of public health, it is essential to monitor exposure levels, establish safe limits, and carry out pollution control measures. Evidence for the connections between ambient exposure to EDCs and illnesses like diabetes, neurological disorders, reproductive issues, inflammation, and compromised immune systems is presented in this research.

### Heavy Metals and their Sources

Metallic elements having high atomic weights and densities greater than 5 g/cm$^3$ are referred to as heavy metals. Their atomic shapes and electron configurations give them special chemical characteristics. Lead (Pb),

cadmium (Cd), mercury (Hg), arsenic (As), and chromium (Cr) are examples of common heavy metals. These metals may be harmful to human health. As heavy metals build up in the body, they cling to cells and interfere with their regular operations. When left untreated, this disturbance can cause symptoms that could be fatal. Complications from heavy metal exposure include birth defects, cancer, vascular damage, neurological diseases, skin sores, immune system dysfunction, and problems with the digestive and kidney systems.[4] These harmful metals pose a serious risk to one's general health because they can enter the body by eating, breathing, or skin absorption. Heavy metals have been thoroughly studied in terms of their toxicity, chemical makeup, and effects on the environment.

Metals that are heavy are essential to many industries. For instance, lead is used in paints, batteries, and pipes; cadmium is utilized in electronics and pigments; and mercury is utilized in fluorescent lights and thermometers. Heavy metals are released into the environment via these activities. Heavy metals can be present in ordinary objects. Lead and other hazardous metals can be found in some jewelry, toys, and cosmetics. Heavy metals can enter our bodies through contaminated food packaging and water pipes. Ecosystems are exposed to heavy metals through the soil, water, and air. Agriculture runoff, smelting, and mining all contribute to soil contamination.[5] Water bodies receive heavy metals from industrial discharges and urban runoff. Research has shown that heavy metal pollution affects aquatic life, vegetation, and wildlife by contaminating soil, water, and sediments in a variety of environments.[5]

Heavy metals are noxious substances that linger. They spend a lot of time in the environment after being released. Their lengthy half-lives make removal difficult. Living things accumulate these metals. For example, tainted water causes fish to accumulate mercury. Up the food chain, the concentration of heavy metals rises as larger organisms eat smaller ones. Heavy metals continually accumulate in tissues, impacting aquatic and terrestrial ecosystems, according to research on bioaccumulation. Because of their ubiquity, durability, and capacity for bioaccumulation, heavy metals represent serious threats to the environment and human health.[6] Comprehending their influence is essential for eco-friendly methods and efficient pollution management.

**Health Consequences of Heavy Metal Exposure**

People today are exposed to heavy metals in a variety of ways. Long-term exposure to heavy metals puts workers in sectors like mining, smelting, and battery manufacture at risk. People who live close to polluted areas or who eat and drink tainted food are at risk of long-term exposure. The health of people is seriously threatened by long-term exposure to heavy metals. Over time, these harmful substances can build up in the body and have a cascade of negative effects. Reactive oxygen species, or ROS, are produced by heavy metals in cells. ROS destroy DNA, lipids, and proteins within the cell. Oxidative stress, which arises from an imbalance between the body's capacity to neutralize reactive oxygen species (ROS) and the amount of ROS produced, is one of the main mechanisms of heavy metal toxicity. This oxidative stress sets up inflammation, a defense mechanism that can become long-lasting and be linked to a number of health problems.

Inflammation results from immunological reactions brought on by prolonged exposure. Chronic inflammation is a factor in many different illnesses. The neurological system is affected by lead and mercury. Lead affects cognitive performance, particularly in young children.[7] Mercury exposure impairs memory, attention, and motor abilities.[8] Lead and cadmium raise the risk of atherosclerosis, heart disease, and hypertension. They cause over production of free radicals and interfere with vascular system. Heavy metals have a big impact on the hormones of reproductive system. Lead and Mercury affect the hormones of female reproductive system and Cadmium is associated with male fertility dysfunction.[9] Cadmium is also known to cause renal impairment and can lead to chronic kidney disease and renal failure.[10] In the end, continued exposure to heavy metals for a long time leads to a number of risks that affect vital organs as well as overall health. There is a dire need to be vigilance to minimize exposure for the benefit of public health.

**Endocrine-Disrupting Roles of Heavy Metals**

Heavy metals are really dangerous to the human health because they have the ability to disturb the subtle balance of hormone

homeostasis. Heavy metals may attack endocrine system at multiple avenues like hormone synthesis, secretion, transport, metabolism, and receptor binding, which may have a detrimental effect on an individual's overall health.

**i. Disruption of Receptor Binding**

Heavy metals can alter the structural makeup or block regular hormone binding to their receptors by attaching them to hormone receptors. For example, Lead (Pb) can hamper estrogen signaling by interacting with the estrogen receptors.[11] This disruption may lead to disturbed hormone levels and consequent effects on their target tissues.

**ii. Enzyme Inhibition**

There are many heavy metals which obstruct the activity of enzymes involved in the synthesis, metabolism, or degradation of hormones. The conversion of steroid hormones is impacted by Cadmium (Cd) inhibiting 17β-hydroxysteroid dehydrogenase.[12] Hormone availability and function are impacted by enzyme activity dysregulation.

**iii. Oxidative Stress and Hormones**

Reactive oxygen species (ROS) are produced by heavy metals, which lead to oxidative stress. Hormone secretion may be impacted by ROS damage to hormone-producing organs (such as the thyroid and adrenal glands). For example, thyroid peroxidase damage and impaired thyroid hormone production are two ways that mercury (Hg) impairs thyroid function.[13]

**iv Endocrine-Disrupting Effects**

Hormones can be mimicked or antagonistic by prolonged exposure to heavy metals. They might change the balance of hormones by acting as endocrine disruptors. Lead, for example, interferes with calcium-dependent hormone release by competing with calcium ions.[14]

**v. Feedback Loops and Hypothalamus-Pituitary Axis**

The hypothalamus-pituitary axis has feedback loops that can be thrown off by heavy metals. Lead, for instance, influences the generation of gonadotropin-releasing hormone (GnRH) in the hypothalamus.[15] This interference affects the levels of sex hormones and results in altered gonadotropin (FSH, LH) release.

## MECHANISMS OF ENDOCRINE DISRUPTION

It's a widely accepted fact that the multifaceted equilibrium of the endocrine system can be disturbed by heavy metals.

A multitude of molecular mechanisms cause many of the damaging health effects associated with heavy metal consumption.

**a) Disruption of receptor binding**

There are many ways by which heavy metals can disrupt hormone receptor function and can cause a host of detrimental health consequences. It is really important to understand these molecular interactions to develop effective strategies to tackle and stop the harmful consequences of exposure to heavy metals.

**i. Receptor Competition**

Receptor competition, is a crucial step in endocrine disruption in which hormones and heavy metals fight for the binding sites of the hormone receptors. This competition for the receptor binding site hinders the normal hormonal signaling pathways, which could have deleterious effects for health. For instance, cadmium can compete with natural estrogen for the estrogen receptor similarly to natural estrogen and even outcompete it.[1] Cadmium also shows potent estrogen-like activity. All these factors could lead to an overabundance of estrogenic effects, which would damaging effects on the reproductive health and increase the risk of hormone-related cancers. Similarly, Lead can compete with calcium ions for the binding sites on the various receptors and can cause damage to the nervous system and bones.[16] Mercury is another heavy metal which disrupt the metabolism of thyroid hormones by competing with enzymes that are dependent on selenium for binding.[17]

**ii. Altered Receptor Conformation**

Some heavy metals such as lead, mercury, and cadmium etc. can cause significant changes in receptor conformation when they enter the body which can cause hormone disruption. These metals have the ability to attach to hormone receptors and modify their structural makeup, which can impair the receptors' normal function. For example, cadmium can bind to estrogen receptors and change the conformation of the receptor by mimicking the structure of zinc, which makes the receptor less able to bind estrogen.[18] Mercury can also alter the structure of thyroid hormone receptors,

causing a disruption in the communication of thyroid hormones. Contrarily, lead can interfere with androgen receptors, which can lead to abnormal testosterone signaling.

**iii. Inhibition of Signal Transduction**

Heavy metals cause endocrine disruption by inhibition of signal transduction, particularly when heavy metals interfere with receptor binding. Heavy metals including lead, arsenic, and cadmium can hamper the normal functioning of intracellular signaling networks. For example, cadmium has the ability to prevent second messengers from activating when it is attached to hormone receptors, which is required for the downstream signaling cascade.[19] Lead can affect the function of many enzymes and proteins that depend on calcium as a signaling molecule by interfering with the Calcium signaling pathways.[19] Arsenic can inhibit the insulin receptor-related signal transduction pathways thus leading to impaired glucose metabolism.[20]

**iv. Epigenetic Modifications**

Epigenetic alterations can be one more reason of endocrine disruption, especially when it comes to changing receptor binding. Arsenic and Mercury can cause these epigenetic changes via modifying the process of DNA methylation, histone modification, and noncoding RNA expression. For example, it is shown in studies that arsenic exposure modifies normal binding mechanisms through the hypermethylation of genes critical to hormone receptor function.[21] Mercury, on the other hand, can change the structure of the chromatin and affect receptor accessibility by interfering with histone acetylation.[22] These epigenetic modifications alter the expression of genes, disturbing hormone balance and function permanently without altering the DNA sequence in the genetic code. Such disruptions may lead to disruption in the reproductive system, developmental challenges, and increased vulnerability to health.

**v. Cross-Talk Disruption**

Heavy metals may cause the complex process of cross-talk disruption, a mechanism of endocrine disruption in which interactions between many signaling pathways occur which can lead to hormonal abnormalities. Lead and Cadmium are the two major heavy metals that are known to play a role in this process. For instance, by activating the estrogen receptor (ER), Cadmium can mimic the effects of estrogen.[23] Cadmium can also hinder other hormone signaling pathways, such as those that are involved glucocorticoid receptors (GR).[24] Together the GR and ER pathways can interact to weakening the body's immune system against infection and during times of stress. Lead is another heavy metal that can disturb the thyroid hormone receptor (THR) and interfere with thyroid hormone transmission. Thyroid hormones signaling is very essential for energy metabolism and growth of the body. This disruption may result in developmental issues and mental disabilities.

**vi Redox Imbalance**

When environmental pollutants such as heavy metals, including cadmium and mercury, induce oxidative stress, there is a disruption in the balance between reactive oxygen species (ROS) and the body's antioxidant defenses.[25] This redox imbalance could modify hormone receptors, including androgen or estrogen receptors, thereby diminishing their capacity to bind with the corresponding hormones. For example, the substitution of cadmium for zinc in the zinc finger motifs of hormone receptors can lead to conformational changes that hinder binding.[26] In a similar manner, oxidative changes could hinder the thyroid hormone receptor's capacity to control metabolism.

## ENZYME INHIBITION

Heavy metals have the potential to disrupt the endocrine system by interfering with essential enzymes that play a crucial role in hormone production, metabolism, or degradation. It is crucial to remember that the consequences of enzyme inhibition brought on by heavy metals can be varied and intricate. These metals can interact with endocrine system enzymes that can have a chain reaction impact on levels of hormones and signaling pathways. Understanding these pathways is very essential to develop effective strategies to tackle the detrimental consequences of heavy metal.

**i. Enzyme Inhibition in Hormone Synthesis**

Heavy metals can attach themselves to the enzymes which are required for the biosynthesis of hormones and inhibit the enzymes from

catalyzing the essential processes. For instance, The most severely harmed mechanism is male reproductive function, since exposure to Cd has been linked to infertility on multiple occasions.[27,28] Because of its ability to imitate other divalent metals, cadmium can obstruct some processes. Research has shown that this metal can cause oxidative stress and the production of reactive oxygen species (ROS), and it can also indirectly limit the action of antioxidant enzymes and proteins that have zinc finger motifs.

Enzyme function may be disrupted by some heavy metals that bind to enzymes at locations other than the active site, changing the structure of the enzyme. This may result in decreased enzyme activity or their total inactivation. Lead has the ability to block δ-aminolevulinic acid dehydratase (ALAD)[29], an enzyme that is essential for the production of heme, an element that is part of the Thyroid Peroxidase (TPO) enzyme. Tri-iodothyronine and tetra-iodothyronine, two thyroid hormones, are synthesized with the help of an enzyme called TPO. Therefore, Pb-induced suppression of ALAD results in heme shortage and compromised hormone synthesis.

**ii. Enzyme Inhibition in Hormone Metabolism**

Interfering with the breakdown of hormones: Heavy metals have the ability to block the enzymes that metabolize hormones, which causes an excess of biological activity and hormone buildup. For example, this enzyme, which is essential for transforming weak androgens into strong estrogens, is inhibited by Cd. Cd alters estrogen levels by interfering with 17β-Hydroxysteroid Dehydrogenase (17β-HSD).

Modifying the activation or deactivation of hormones: Certain enzymes are in charge of changing precursors of inactive hormones into active hormones and vice versa. Hormone abnormalities can result from heavy metal disruption of these mechanisms.

Because aromatase converts androgens to estrogens, lead (Pb) inhibits it, which may have an impact on estrogen levels and may compromise reproductive health. Monoamine Oxidase (MAO), which metabolizes neurotransmitters, is inhibited by prolonged exposure to Magnesium (Mg), which affects neurotransmitter balance and mental wellness.[30]

**iii. Enzyme Inhibition in Hormone Degradation**

Heavy metals can cause excessive hormonal activity by extending the half-life of hormones and blocking the enzymes responsible for hormone breakdown. This may be a factor in a number of endocrine-related illnesses. Because it inhibits glucuronosyltransferases and sulfotransferases, arsenic (As) messes with glucuronidation and sulfation, which affects hormone clearance. Certain P450 isoforms involved in hormone metabolism are inhibited by cadmium (Cd) and lead (Pb). This disturbance changes hormone removal and breakdown. Thyroid hormone balance and in large part metabolism is affected by deiodinase activity that can be interfered with by mercury (Hg).[31] Cadmium affects its action on the Angiotensin converting enzyme (ACE) activity of the Renin Angiotensin System (RAS) pathway.[32] Such disruption may affect blood pressure and hormone control.

## EFFECTS OF HEAVY METALS ON THE IMMUNE SYSTEM

Heavy metals such as lead, cadmium, mercury, and arsenic not only disrupt endocrine functions but are also recognized for their profound impact on the immune system. Their immunotoxicity can manifest through several mechanisms, affecting both innate and adaptive immunity.

**1. Heavy Matels Induced Thymic Atrophy and Histopathological changes.**

***1.1. Structural alterations in the thymus induced by Heavy Metal Exposure***

Chronic exposure to heavy metals such as cadmium (Cd), lead(Pb), and, mercury(Hg) induces significant structural damage to the thymus, primarily characterized by cortical thinning and reduce cellularity. Thymus, a vital lymphoid organ for T-cell development, undergoes histopathological changes when exposed to these toxic elements. Heavy disrupt thymocytes through oxidative stress and mitochondrial dysfunction, while simultaneously damaging the cortical epithelial networks essential for T-cells selection. This leads to pronounced cortical thinning, which impairs the thymus ability to support proper T-cell proliferation and positive selection.

In parallel, heavy metals cause a marked reduction in thymic cellularity through multiple mechanism. They inhibit thymocyte proliferation by inducing DNA damage and cell cycle arrest, deplete hematopoietic precursors from the bone marrow, and disrupt critical chemokine signaling pathways like CCL21 and CXCL12 that guide thymocyte migration. the combined effect of these processes results in fewer thymocytes and diminished T-cell output, compromising immune function. Different heavy metals exhibit distinct yet synergistic effect: cadmium promotes cortical atrophy by upregulating proapoptotic proteins like Bax and caspase-3 which lead reduces thymic weight and cellularity by interfering with glucocorticoid signaling even at low does; and mercury induces lymphoid hypocellularity by suppressing NF-$_K$B and depleting antioxidants.

These structural alterations have serious long-term consequence, including immunodeficiency due to reduced naïve T-cell production and potential autoimmunity from impaired negative selection of autoreactive T-cell. Furthermore, possible therapeutic interventions include antioxidant administration (e.g., N-acetylcysteine) to counteract damage, Zinc supplementation to displace toxic metals and support thymic regeneration, and cytokine-based therapies (e.g., IL l7) to restore thymopoiesis. Understanding this metal induced changes is crucial for developing strategies to protect thymic function in exposed population, particularly in environmentally high-risk area.

**Table 1:** Effects of Heavy Metals on The Endocrine Glands

| Endocrine Gland | Heavy Metal | Effects on the Endocrine Gland |
|---|---|---|
| Thyroid Gland | Lead, Cadmium, Mercury | Disrupts thyroid hormone production, metabolism and signalling, leading to hypothyroidism or hyperthyroidism, metabolic disorders, developmental delays, and goiter. |
| Adrenal Glands | Lead, Cadmium | Impairs adrenal gland function, affecting cortisol and adrenaline production, stress response, immune function, and blood pressure regulation. |
| Pancreas | Arsenic, Cadmium | Interferes with insulin production and secretion, contributing to diabetes mellitus and impaired glucose metabolism. |
| Reproductive Organs | Lead, Mercury | Disrupts ovarian and testicular function, leading to infertility, menstrual irregularities, and decreased sperm quality. |
| Pituitary Gland | Heavy Metals (General) | Affects the regulation of other endocrine glands, causing hormonal imbalances, and impacting growth, metabolism, and reproductive health. |

### *1.2. The Role of Metallothionein and Heavy Metal Accumulation in Thymus Gland Dysfunction*

The thymus gland, a critical organ for t cell development and immune function, is highly susceptible to heavy metal toxicity. Metallothionein's (MTs), small cysteine-rich proteins play a dual role in both protecting against and exacerbating metal induced damage in the thymus. Under normal conditions, MTs bind essential metal zinc (ZN+2), and copper (cu+2), maintaining cellular homeostasis and scavenging harmful reactive oxygen species (ROS). However, expression to toxic heavy metals such as cadmium (Cd), lead (Pb), and mercury (Hg) leads to their accumulation in thymic tissue, where they compete with physiological metals for MT binding. When MTs become saturated, excess free metals, disrupt thymocytes maturation, induce oxidative stress, and trigger apoptotic pathways, resulting in thymic atrophy and immunosuppression. Additionally, heavy metals interfere with thymic hormone production (e.g., thymulin), further impairing immune competence. Understanding the interplay between MTS and metal accumulation is crucial for developing strategies to mitigate heavy metal induced thymic damage, particularly in vulnerable populations exposed to environmental pollutants.

**Table 2:** Immunotoxin Effects of Major Heavy Metals: Mechanisms, Biomarkers, and Clinical Manifestations

| Heavy Metal | Innate Immune Effects | Adaptive Immune Effects | Cytokine Alterations | Autoimmunity Risk | Notable Biomarkers | Clinical Manifestations |
|---|---|---|---|---|---|---|
| **Lead (Pb)** | ↓ Phagocytosis by macrophages, ↓ Neutrophil function | ↓ T-cell proliferation Altered Th1/Th2 balance (Th2 bias) | ↑ IL-4, IL-10 ↓ IFN-γ | ↑ Autoantibody production | Elevated IgE Reduced CD4/CD8 ratio | Increased infection risk, asthma, allergies, autoimmunity |
| **Mercury (Hg)** | Impaired dendritic cell maturation, ↓ NK cell cytotoxicity | ↓ CD4+ T-cell count Abnormal antibody production | ↑ TNF-α, IL-6, ↑ pro-inflammatory cytokines | ↑ Risk in genetically susceptible individuals (e.g., SLE) | Increased ANA Altered cytokine profile | Lupus-like symptoms, chronic inflammation |
| **Cadmium (Cd)** | ↓ NK cell activity, ↓ Macrophage function | ↓ B-cell antibody production T-cell apoptosis | ↑ IL-1β, ↑ IL-6, Impaired cytokine signaling | ↑ Autoimmunity potential | Reduced total IgG Increased Treg cells | Frequent respiratory infections, autoimmune markers |
| **Arsenic (As)** | Suppressed dendritic cell maturation, ↓ Neutrophil migration | ↓ Plasma cell formation ↓ Immunoglobulin synthesis | ↑ Pro-inflammatory cytokines, Disrupted chemokine signaling | ↑ Autoimmune thyroid disease | Decreased IgM/IgA Elevated inflammatory markers | Immunosuppression, autoimmune thyroiditis |

↑ = Increased, ↓ = Decreased, ANA = Antinuclear antibodies, Treg = Regulatory T cells, SLE = Systemic lupus erythematosus

## CONCLUSION

Why heavy metals cause endocrine disruption is critical because they represent a major threat to human health and ecosystems. Lead, Mercury and Cadmium are heavy metals that imitate or interact with hormones. The results can be deadly the development, the immune system and the reproductive system can all be affected. This imbalance may have varied consequences including thyroid dysfunction and developmental cerebral deficit as well as metabolic disability. In addition, these metals bioaccumulate in the food chain and have the potential to totally disrupt ecosystems, amplifying the impact on species. Crucially, these risks should be advocated for by monitoring, research and proposed regulatory initiatives aimed at their reduction. We expect that application of the increasing research efforts will allow us to understand the mechanics of endocrine disruption and develop useful mitigation strategies. On one hand, vigorous monitoring programs competent to detect and trace the presence of metals in the environment can alert cleanup before the heavy metals have an opportunity to settle and cause irreparable environmental or human health damage. Ecosystems can be also underpinned by robust regulatory framework assuring public health, and more stringent limits on heavy metal emissions. To do this, governments, scientific groups, and environmental organizations need to work together to create comprehensive policies. To protect human health, promote environmental sustainability and secure a safer future for all living things, we can lead with research, oversight and regulation. What really matters is that we find some sort of balance between the development of industry and protection of our ecological systems.

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