

50 years of trace element pollution: mammals as biomonitors of environmental degradation in Latin America

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Mammals are excellent biomonitors for pollutants such as trace elements; however, there is a lack of studies on this subject in wild mammals across Latin America. This review provides a comprehensive and updated overview of the current state and trends in mammalian toxicology, offering an integrative regional perspective. A systematic literature review was conducted, identifying and synthesizing data on date of publication, country of study, analyzed pollutants, taxonomic group and trophic guild involved, biological matrix used, analytical techniques, and sample origin. Publications show a constant increase in their number and diversity. However, research remains concentrated in high-biodiversity or polluted areas within large countries such as Brazil, Mexico, and Argentina, leading to significant geographical biases. At present, the most frequently analyzed elements have been Hg, Pb, and Cd, reflecting their relevance as environmental pollutants generated from extractive industries and fossil fuel combustion. Aquatic carnivores are highly susceptible to bioaccumulation, making the order Cetacea and the piscivorous trophic guild the most studied groups, underscoring their well-documented issue of mercury contamination in aquatic ecosystems. On the other hand, terrestrial mammals remain comparatively understudied. Due to their central role in metabolic pathways and detoxification of contaminants, liver and kidney have been the most analyzed matrices. Atomic absorption spectrometry has been the most frequent quantification technique, favored for its suitable cost-benefit balance. Future research should incorporate non-invasive techniques and reevaluate the importance of scientific collections, as they offer valuable historical baselines for ecotoxicological studies. We strongly recommend prioritizing further research in mammal species populations living in urban areas and mining regions, to better understand and mitigate the ecological impacts of metal pollution in these threatened ecosystems.

Keywords: biomonitoring, cadmium, lead, mercury, nickel, vanadium

Los mamíferos son excelentes biomonitores de contaminantes, tales como los elementos traza, sin embargo, existe una falta de estudios sobre este tema en mamíferos silvestres de América Latina. Esta revisión proporciona una visión integral del estado y las tendencias actuales en toxicología de mamíferos, ofreciendo una perspectiva regional integradora. Se realizó una revisión sistemática de la literatura, identificando y sintetizando datos sobre: año de publicación, país de estudio, elementos analizados, grupo taxonómico, matriz biológica, gremio trófico, técnica analítica y procedencia de los especímenes. Las publicaciones muestran un aumento constante en número y diversidad. Sin embargo, la investigación se concentra en áreas de alta biodiversidad o bien, contaminadas, dentro de países extensos como Brasil, México y Argentina, generando sesgos geográficos significativos. Los elementos más analizados son Hg, Pb y Cd, reflejando su prevalencia en industrias extractivas y combustión de combustibles fósiles. Los carnívoros acuáticos son altamente susceptibles a la bioacumulación, haciendo del orden Cetacea y del gremio trófico piscívoro los grupos más estudiados. Este enfoque acentúa el problema bien documentado de la contaminación por mercurio en ecosistemas acuáticos, mientras que los mamíferos terrestres permanecen comparativamente poco estudiados. El hígado y el riñón son las matrices más analizadas, lo que concuerda con su papel central en el metabolismo y la desintoxicación de contaminantes. La espectrometría de absorción atómica es la técnica de cuantificación más frecuente, favorecida por su costo-efectividad. Las investigaciones futuras deberían incorporar técnicas no invasivas y reevaluar la importancia de las colecciones científicas, pues ofrecen valiosas líneas base históricas para estudios ecotoxicológicos. Recomendamos incrementar la investigación en áreas urbanas y mineras para comprender y mitigar los impactos ecológicos de la contaminación por metales en estos ecosistemas amenazados.

Palabras clave: biomonitoreo, cadmio, mercurio, níquel, plomo, vanadio.

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Currently, some of the most ubiquitous pollutants derived from human activity are toxic metals and metalloids. These trace elements (Fe, Cu, Mn, Hg, Ni, Zn, Cd, Cr, Al, Pb, Sn, Ag, V, Au, Ga, Sb, As, Ti, Sr and Co) are major byproducts of mining,

industrial operations, and fossil fuel combustion ([Heim and Schwarzbauer 2013](#); [Kozłowski et al. 2014](#); [Buriticá 2019](#); [Jiang et al. 2019](#)). Furthermore, they are susceptible to bioaccumulation in living tissues and biomagnification

across trophic chains. This phenomenon poses a substantial threat to wildlife and human populations, as chronic or acute exposure to these substances can lead to poisoning (Nordberg 2001; Gall et al. 2015).

The detrimental health effects of trace elements on humans have been recognized since ancient times and were extensively studied throughout the 20th century (Dooyema et al. 2012; Wilkomirski 2013). In contrast, their consequences for wildlife have been addressed more recently using distinct methodologies, among which biomonitoring is the most frequent (Asif et al. 2018).

A biomonitor is an organism that, due to its ecological traits, exhibits high sensitivity to environmental changes and responds to them gradually as to specific stimuli (Capó 2002). The response of a bioindicator reflects the impact of the perturbation on other elements within its community, as it is sensitive enough to display quantifiable effects yet sufficiently tolerant to survive at concentrations that would be lethal to other species (Markert et al. 2012).

An effective biomonitor exhibits a correlation between the environmental concentration of a contaminant and its concentration within the organism's tissues (Gorman and Conway 2005). Additionally, basic aspects of its biology are well-documented; it also possess a long life cycle with distinct developmental stages. Species that are readily available, easy to handle, provide ample tissue samples, and have a broad geographical distribution are preferred (Kolf-Clauw et al. 2007; Wilkomirski 2013). Mammals generally fulfill these criteria. Moreover, the evolutionary proximity of some mammal species to humans renders them particularly relevant study subjects, positioning them among the most utilized bioindicators (Tataruch and Kierdorf 2003). An additional advantage of mammals is the presence of hair, which shows a robust correlation with internal matrices such as liver, blood, and kidneys (Brait et al. 2009; McLean et al. 2009). Hair also accumulates metals throughout its growth and can be sampled in the field or from scientific collections without harming the specimens (Flache et al. 2015).

Frequently, the use of mammals as biomonitors has been concentrated in Global North countries, which created a significant knowledge gap compared to the rest of the world (Kalisińska 2019; López-Berenguer et al. 2020). Although improvements in instrumental sensitivity and cost have facilitated studies in other regions, such as Latin America, ecotoxicological investigations are still scarce, and a comprehensive compilation of the state of knowledge on mammals in this region is lacking (Di Marzio et al. 2019; Canham et al. 2020). This study addresses this critical gap by providing an updated, integrative regional synthesis of metal biomonitoring in wild mammals across Latin America, consolidating fragmented information from diverse sources to establish a cohesive baseline for future research. This topic is relevant, as the study area hosts the highest number of megadiverse countries globally, while simultaneously experiencing a severe crisis of species loss and anthropogenic pollution.

Historically, gold and silver mining in Latin America have been primary sources of contamination by toxic elements such as mercury since the 16th century; however, from the second half of the 20th century onward, increased fossil fuel exploitation, industrialization, mining, agrochemical use and urban growth have led to elevated emissions of multiple trace elements. Thus, understanding the distribution and biological effects of these pollutants in mammalian fauna is essential for informing conservation strategies and environmental policy in this region (Driscoll et al. 2013).

The objectives of this work are: to synthesize relevant data from the literature, to describe the main groups of mammals employed as biomonitors, the characteristics of the most studied areas, and the regions with information gaps. We also emphasize the use of different biological matrices, analytical techniques employed, and associated potential pollution sources. By systematically identifying taxonomic, geographical, and methodological trends, this review offers a critical evaluation of existing research, while highlighting priority areas for future investigation. Finally, we discuss emerging approaches in the ecotoxicological study of mammals, highlighting historical trends, the need for targeted research in areas affected by specific issues like mining or urbanization, and the future challenges in this field.

Materials and methods

A literature search was conducted to identify digital publications on mammals as biomonitors of metals in Latin America. The study area was defined as the region comprising Mexico, Central America, the Caribbean, and South America, including their respective islands and territorial waters. The search spanned publications from 1960 to 2025, and the study subjects included all groups of wild mammals from the region. Studies involving only laboratory specimens and humans were excluded.

The search included journal articles and theses; review articles were considered in a separate category. The search engines used were Google Scholar, Scopus, PubMed, and the internal search portals of institutions with which one or more authors from previously identified studies were affiliated. The primary search string for all search engines was: ("mammals" OR "wild mammals") AND ("metals" OR "heavy metals" OR "trace elements" OR "toxic metals" OR "biomonitor" OR "sentinel species") AND ("Latin America" OR "Caribbean" OR "Antigua and Barbuda" OR "Argentina" OR "Bahamas" OR "Barbados" OR "Belize" OR "Bolivia" OR "Brazil" OR "Chile" OR "Colombia" OR "Costa Rica" OR "Cuba" OR "Dominica" OR "Dominican Republic" OR "Ecuador" OR "El Salvador" OR "Grenada" OR "Guatemala" OR "Guyana" OR "Haiti" OR "Honduras" OR "Jamaica" OR "Mexico" OR "Nicaragua" OR "Panama" OR "Paraguay" OR "Peru" OR "Saint Kitts and Nevis" OR "Saint Lucia" OR "Saint Vincent and the Grenadines" OR "Suriname" OR "Trinidad and Tobago" OR "Uruguay" OR "Venezuela").

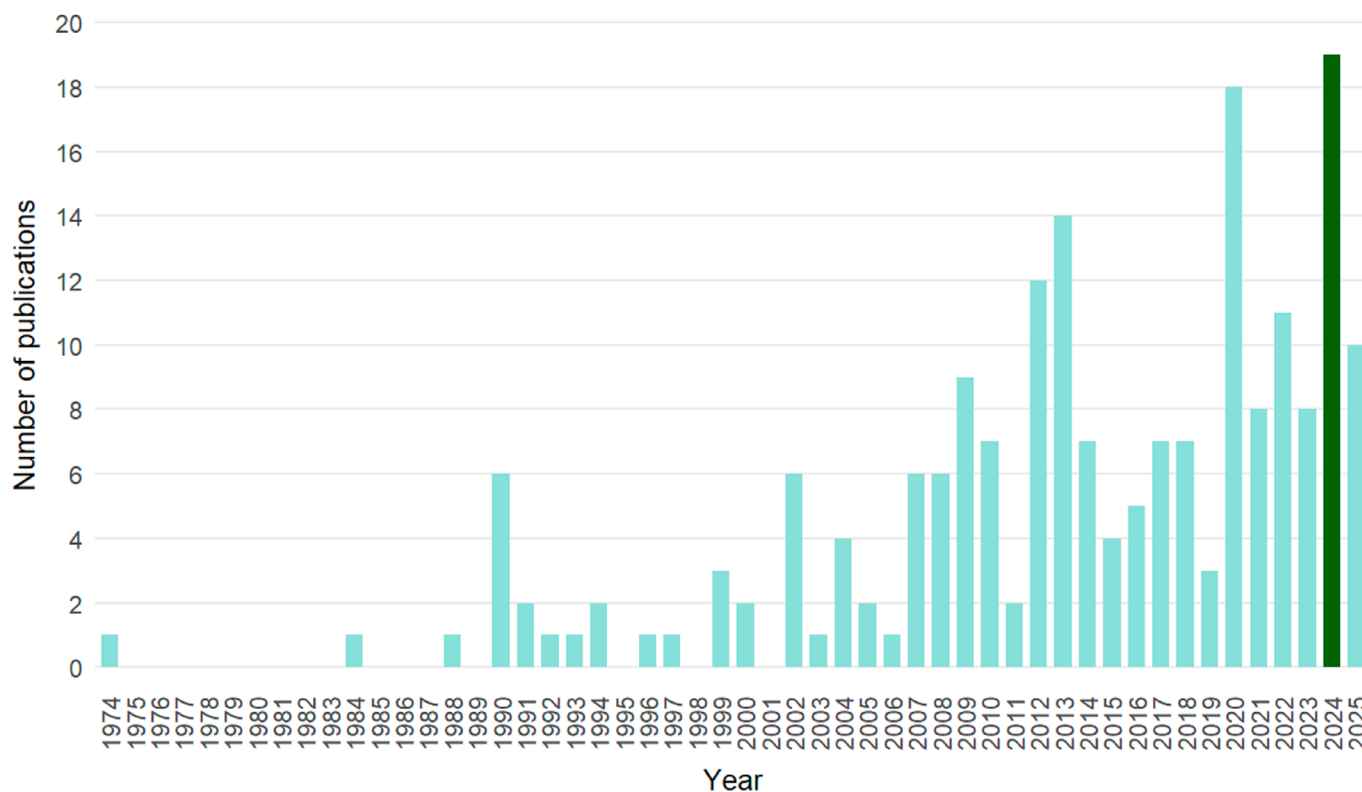


Figure 1. Number of studies on trace element biomonitoring in wild mammals in Latin America from 1974 to 2025.

A complementary search was performed, targeting 22 specific metals with the following search string: ("mammals" OR "wild mammals") AND ("aluminum" OR "antimony" OR "arsenic" OR "cadmium" OR "chromium" OR "cobalt" OR "copper" OR "gallium" OR "gold" OR "iron" OR "lead" OR "manganese" OR "mercury" OR "molybdenum" OR "nickel" OR "selenium" OR "silver" OR "strontium" OR "tin" OR "titanium" OR "vanadium" OR "zinc") AND ("Artiodactyla" OR "Carnivora" OR "Cetacea" OR "Chiroptera" OR "Cingulata" OR "Didelphimorphia" OR "Diprotodontia" OR "Eulipotyphla" OR "Lagomorpha" OR "Microbiotheria" OR "Paucituberculata" OR "Perissodactyla" OR "Pilosa" OR "Primates" OR "Rodentia" OR "Sirenia"). The search was performed in triplicate using keywords in Spanish, Portuguese, and English. The final search date was December 20, 2025.

To eliminate duplicate data and discrepancies, data from each article were reviewed to verify that the information provided by each study was original. Only articles published in peer-reviewed journals and undergraduate or graduate theses that had undergone committee review were included. Undergraduate dissertations not requiring a thesis defense, scientific outreach texts, and works lacking data on the presence or quantification of trace elements were excluded. Additionally, studies conducted on species living exclusively under domesticated or captive zoo conditions were also removed. Chemical speciation of the analyzed elements was not considered, as the majority of original articles did not make this distinction.

The retrieved results were organized according to the following criteria: year of publication; country of origin;

chemical element(s) analyzed; taxonomic group(s) included in each publication; biological matrix used; trophic guild(s); quantification or detection technique; and the system of origin (e.g., terrestrial, aquatic). Furthermore, records exceeding reference limits associated with neurotoxicity in mammals (EPA 2022; FAO/WHO 2024) were selected (Tables 1 and 2; Supplementary data). Essential elements such as Fe, Mn, Zn, and Cu are natural constituents of living organisms but were included in this review because they exhibit potential toxicity in mammals when present in excessive amounts, particularly due to anthropogenic sources.

To homogenize the data across different tissue types, all concentrations were expressed in wet weight, following tissue-specific conversion factors established by Lu and Kacew (2009) and Landis et al. (2011): Water content correction factors applied were 0.745 for liver, 0.78 for kidney, and 0.10 for hair. Based on these results, the species with the highest pollutant concentrations were identified.

Results

A total of 197 digital records were obtained, of which 160 correspond to journal articles and 17 to theses. Additionally, 20 global or local reviews that include information on Latin America have been published. Because they lack experimental data, reviews were not included in the numerical analysis of the present article. The most frequently used language was English, followed by Spanish and Portuguese. The earliest record for marine mammals corresponds to Gaskin et al. (1974), while the oldest for terrestrial mammals is that of Burger et al. (1994). Since then, a consistent increase in the

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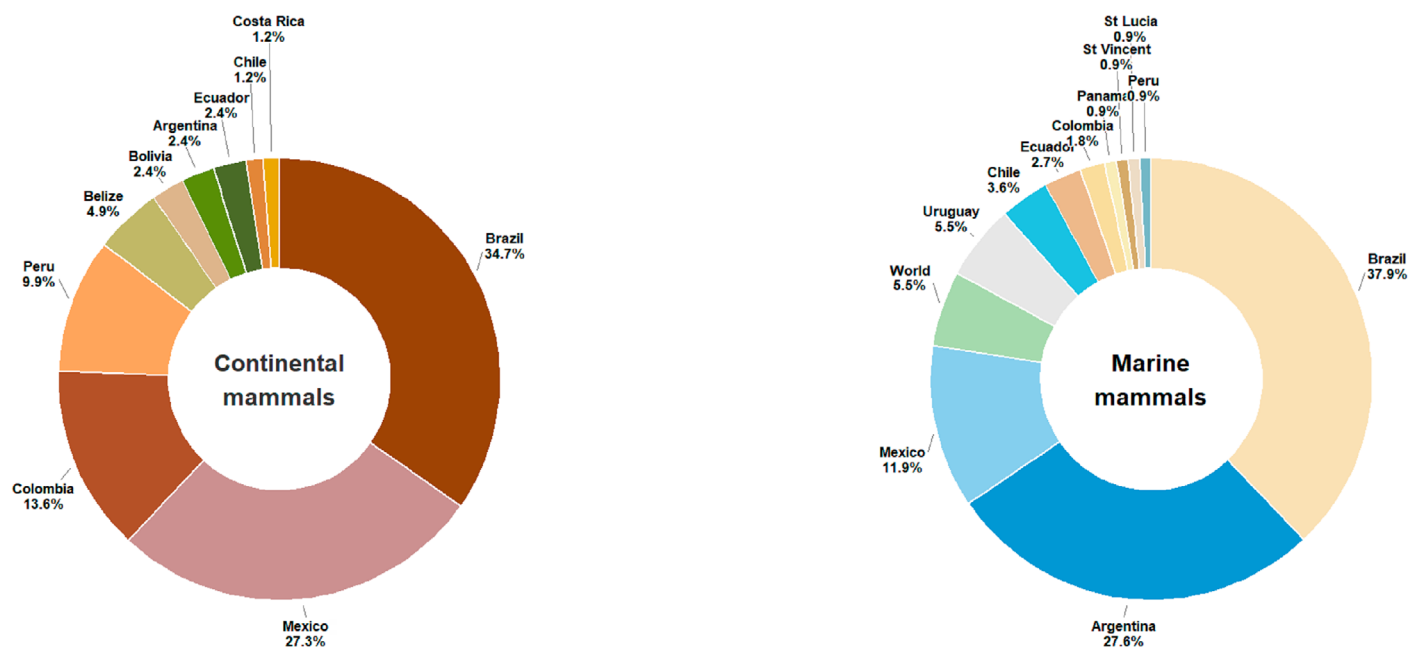


Figure 2. Number of articles and theses per country on mammals as bioindicators of trace elements in Latin America.

number and diversity of published articles on the topic has been observed (Figure 1). The year with the highest activity in this field was 2024, with 19 articles.

Geographically, studies are concentrated in the largest and most populous countries in the region. Consequently, Brazil, Mexico, and Argentina account for over 70% of the total publications (Figure 2). Within these countries, the Amazon River Basin and the Cerrado in Brazil, as well as the mining systems of Morelos in Mexico, are the most studied terrestrial areas. Meanwhile, the coasts of Argentina and Brazil have been the most significant areas for the study of marine mammals.

In total, 22 trace elements have been identified, with mercury being the most frequently studied, followed by cadmium, lead, copper, and zinc (Figure 3). The most frequent objective of the publications was the analytical detection of trace element presence (173), followed by the study of damage biomarkers (22), while the least common objective was the implementation of exposure assays to complement field data (4). Research on this topic has involved seven mammalian orders; the most studied order is Cetacea, and within it, odontocetes have been the subject of the most assessments (Figure 4a). In turn, studies on bat communities have simultaneously involved the largest number of species and trophic guilds from the same locality. Piscivorous species have received particular attention as biomonitors for mercury, whose accumulation pathway often involves aquatic systems (Figure 4b). Quantification in internal organs has been concentrated in the liver and kidney, which are key structures in the transformation and elimination of metallic elements. In turn, hair is the most utilized integumentary annex (Figure 5).

Various techniques have been employed for the detection and quantification of metals. The most used has been Atomic Absorption Spectrometry (AAS), with 112 mentions (Figure 6). The analyzed samples were mostly obtained through direct field collection of specimens. A fraction of the studies utilized material previously housed in scientific collections. The best-studied ecosystems are marine and coastal systems (Figure 7). In contrast, arid and semi-arid zone ecosystems, as well as tropical sub-deciduous forests, have the lowest number of studies.

Discussion

The primary focus of the recorded studies has been to quantify trace elements and infer their impact on wild mammals, with pollution often linked to specific activities like mining and urbanization. Although contamination sources have existed for centuries in Latin America, they intensified markedly during the second half of the 20th century, driven by rapid industrial expansion and resource extraction. Early studies from this review identify these specific sources ([Moreno et al. 1984](#); [Peña et al. 1988](#)).

Geographically, research has concentrated in Brazil, Mexico, and Argentina—countries containing extensive natural areas threatened by human activities alongside some of the region's most densely populated urban zones with high land conversion rates ([Di Marzio et al. 2019](#)). The Amazon River Basin exemplifies this pattern, being one of the most researched areas from a toxicological perspective due to its vast biodiversity and intense anthropogenic pressure. Notable studies in this region include [Contreras Luna and Chavez Estibur \(2017\)](#) and [Moreno-Brush et al. \(2018\)](#), who quantified mercury in bats from the Madre de Dios River Basin in Peru. The work of [Dias Fonseca \(2004\)](#) and [Dias Fonseca et](#)

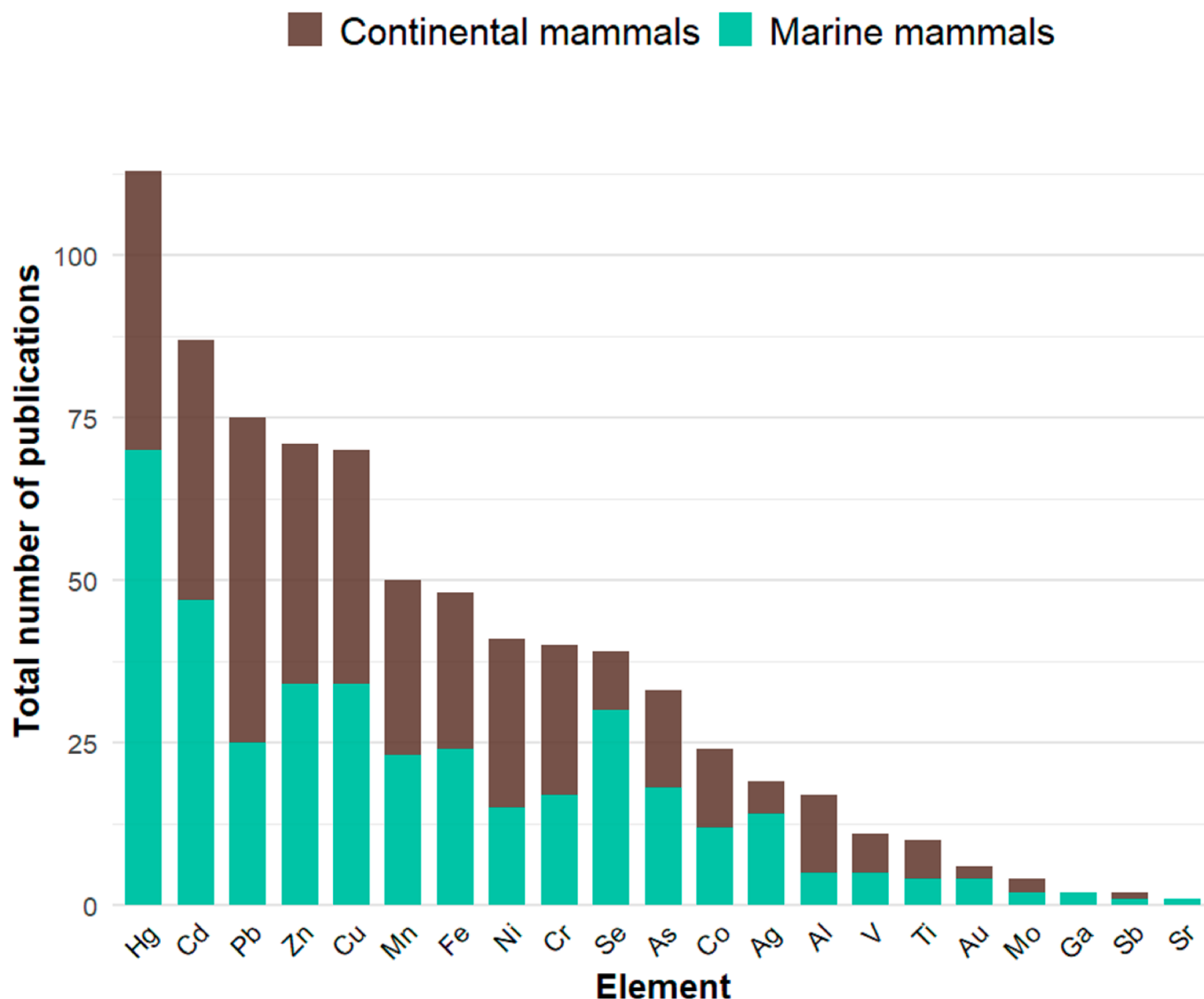


Figure 3. Trace elements quantified in wild mammals in Latin America from 1974 to 2025.

[al. \(2005\)](#) on mercury accumulation in giant otters (*Pteronura brasiliensis*) is also significant. These studies are crucial as both areas experience metal contamination from artisanal mining, a widespread activity estimated to release over 2.5 tons of mercury annually into Amazonian rivers ([Lucchini et al. 2025](#)). This not only poses a direct threat to aquatic and terrestrial food webs but also establishes a benchmark for studies in tropical zones worldwide. On the other hand, Central America and the Caribbean have fewer publications, and countries with significant mining impacts—such as Bolivia, Chile, and Peru—would benefit from implementing wildlife metal biomonitoring programs.

Globally, mercury, lead, and cadmium are among the most studied contaminants, with established environmental and biological thresholds due to their health effects ([Lewis et al. 2001](#); [FAO/WHO 2024](#)). Latin America follows this trend, with these elements being the most frequently quantified and their presence is common in most multi-element studies. This focus is justified, as Cd, Pb, As and Hg are associated with mining, an activity with profound

historical and economic significance for the region and the continent ([Di Marzio et al. 2019](#)). Furthermore, Pb, Hg, Cd, Al, As, Mn and Ti are directly associated with neurotoxic effects in mammals. However, this concentration on a few elements may overlook the potential synergistic effects of metal mixtures prevalent in contaminated sites, as well as emerging contaminants such as titanium, vanadium, and gallium, whose effects on wildlife remain poorly described.

In marine environments, most studies have documented bioaccumulation of Hg, Pb, Cd, and As. Beyond dietary influences, identified point sources include mining, agrochemical use, agricultural burning, and even seafloor tectonic activity (Table 2, Supplementary data). Mercury is the most studied element, and its association with marine trophic chains is widely documented. In the study region, the species in which concentrations above neurotoxic thresholds have been most frequently found are Franciscana dolphin (*Pontoporia blainvillei*) (14 studies) and South American fur seal (*Arctocephalus australis*) (9). Both are marine predators found in cold waters (Table 1 and 2,

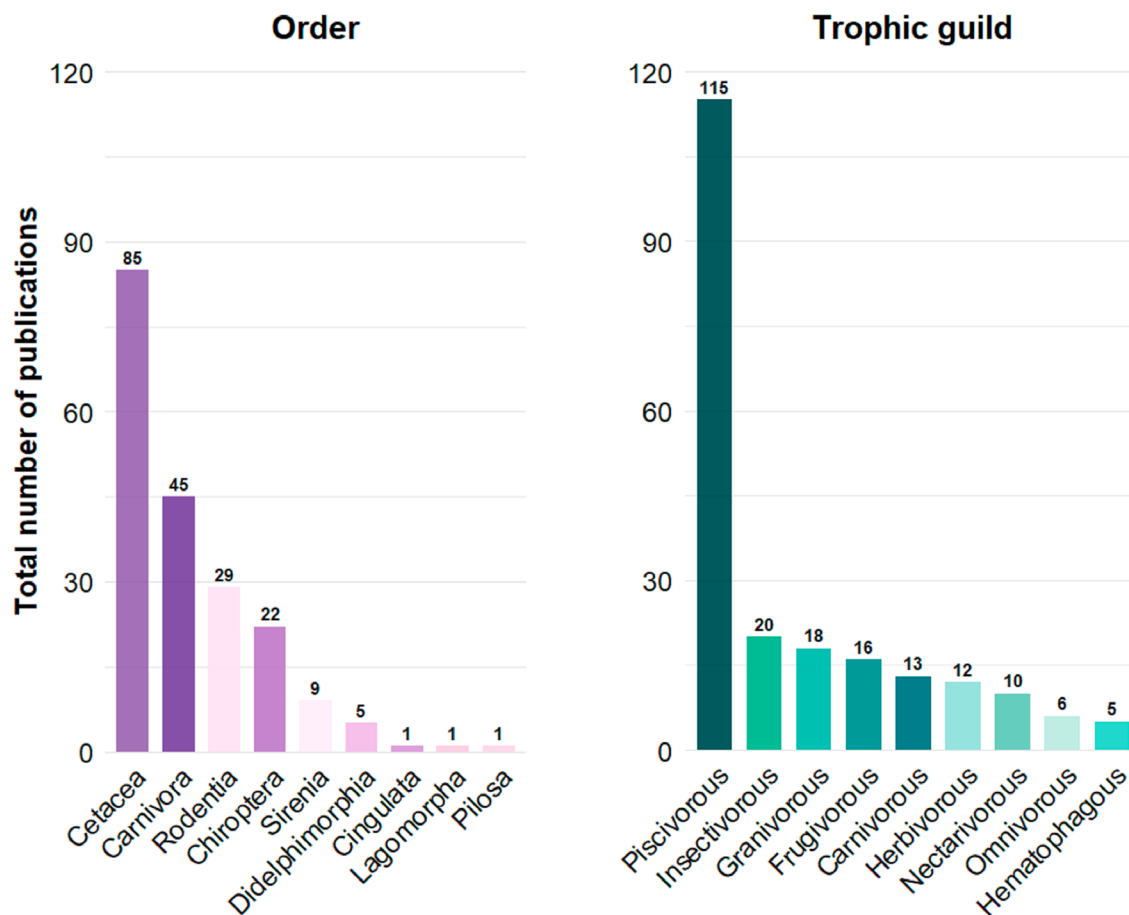


Figure 4. Wild mammal groups in which the presence and effect of trace elements have been evaluated in Latin America from 1974 to 2025. a) Orders; b) Trophic guilds.

Supplementary data). Furthermore, in *P. blainvillei*, mercury has been recorded at concentrations above the toxic limit even in fetuses, highlighting this species' vulnerability and the urgency for better environmental practices and policies (Romero *et al.* 2016).

In terrestrial systems, insectivorous bats such as Brazilian Free-tailed bat (*Tadarida brasiliensis*), Black myotis (*Myotis nigricans*), and Velvety Free-tailed bat (*Molossus molossus*) have proven to be efficient biomonitors for lead, as their concentration in liver and hair is consistently higher in urban centers and agricultural/livestock areas than in other systems (Ramos-H *et al.* 2020; Sánchez-Antonio and Gómez-Martínez 2020; Baquerizo and Salas 2021). In turn, rodents of the genera *Heteromys*, *Peromyscus*, and *Rattus* exhibit lead concentrations exceeding neurotoxic limits, mainly in mining, urban, and industrial influence zones compared to less impacted areas (Mussali-Galante *et al.* 2013; Hernández-Plata *et al.* 2020; Tripodi *et al.* 2020; De la Cruz-Guarneros *et al.* 2021). An additional lead source is hunting ammunition, suggesting that bushmeat consumption may pose health risks to humans who eat it regularly. For cadmium, the kidney serves as the primary target organ, with toxic concentrations detectable earlier than in the liver. The Franciscana dolphin shows the highest recorded cadmium concentrations, with adult females accumulating more than males, suggesting correlations with diet, age, and sexual maturity (Baraj *et al.* 2009; Panebianco *et al.* 2013).

Despite the presence of studies on mercury, lead, cadmium, and arsenic, the effects of other metals like titanium, vanadium, and gallium on wildlife have not yet been fully described. This represents a critical knowledge gap, especially as these metals are increasingly used in modern technologies and may become emerging contaminants. Increasing the number and specificity of studies is essential to understand their mechanisms of action and the true exposure levels for mammals. Such programs could serve as early-warning systems for ecosystem health and human exposure risks.

Taxonomically, research has focused on the orders Cetacea and Carnivora. Their role as predators makes them ideal for toxicological investigation, as they are more susceptible to bioaccumulation of substances like trace elements and pesticides through the abiotic environment and their prey (Kucera 1983). This top-down perspective is vital for understanding contaminant flow through entire ecosystems. In contrast, large continental predators like the jaguar remain understudied. Exceptions include work by May Junior *et al.* (2001) in Brazil and Racero-Casarrubia *et al.* (2012) in Colombia. Their semi-aquatic habits in parts of their range and their status as carnivores make them particularly vulnerable to exposure to metals like mercury (Driscoll *et al.* 2013). The conservation status of jaguar and other continental large predators further underscores the urgency of understanding such anthropogenic threats.

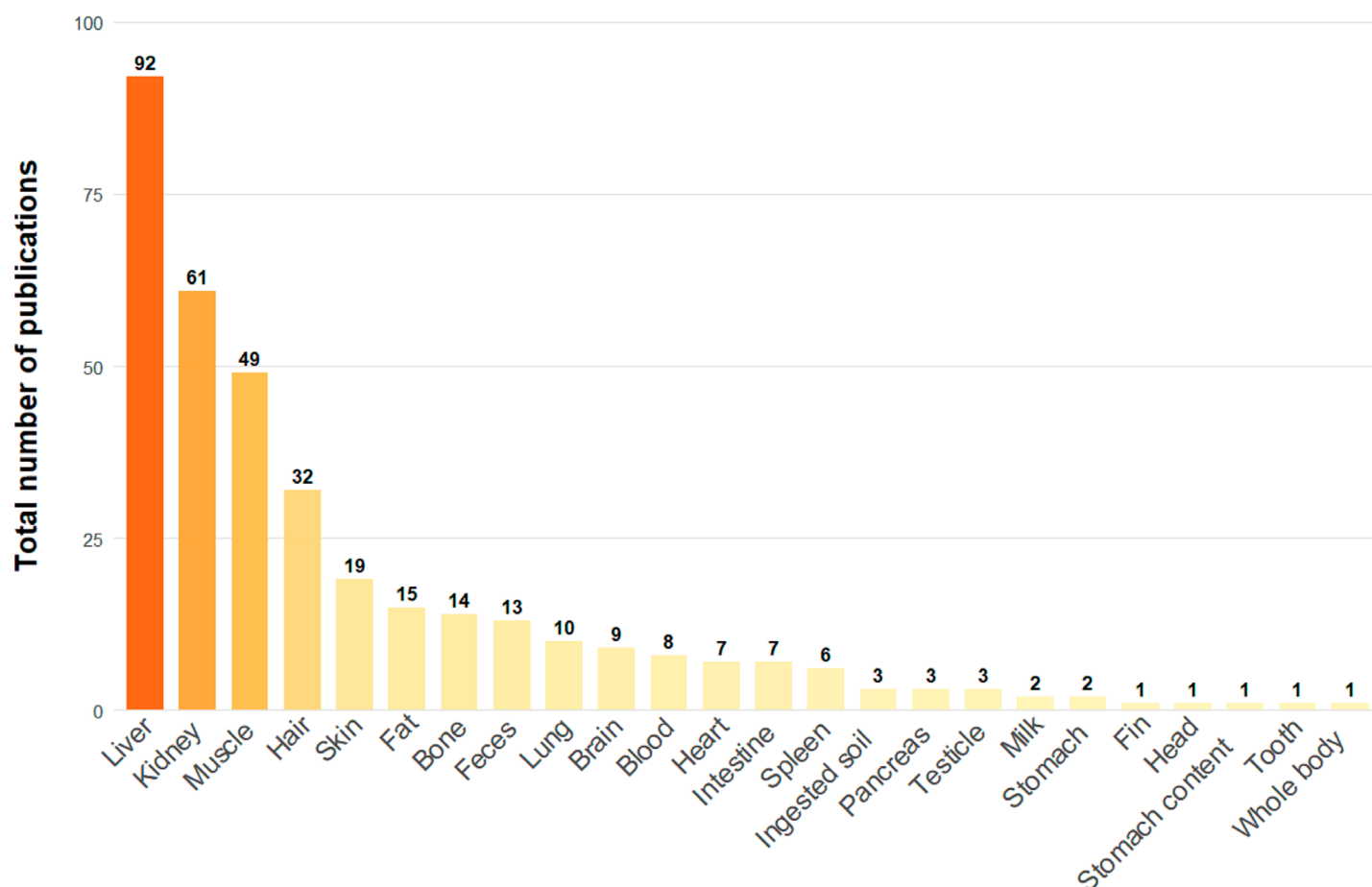


Figure 5. Main matrices used for trace elements quantification in wild mammals in Latin America from 1974 to 2025.

Rodents constitute another group of ecotoxicological importance. Their habits create a link between soil contaminants and higher ecosystem strata (Méndez-Rodríguez and Álvarez-Castañeda 2016; Da Silva *et al.* 2017). As the most abundant mammalian group, with some burrowing species, they are highly susceptible to contamination from extractive industries. Their small home ranges also make them excellent sentinels for local-scale contamination (Smith *et al.* 2002). On the other hand, bats (Chiroptera) offer an additional advantage; by occupying different trophic levels, they provide multiple perspectives on accumulation processes and contaminant pathways within a single study. This makes them powerful, yet underutilized, indicators for assessing landscape-level pollution (Jones *et al.* 2009).

The choice of a biological matrix depends on study objectives and target substances. Trace elements exhibit distinct mechanisms of accumulation, transformation, and elimination, with different tissue residence times, though these processes often involve the liver or kidneys. Therefore, these organs are valuable for assessing recent and chronic exposure and understanding metabolic pathways (Akerstrom *et al.* 2017).

Hair is an excellent indicator of endogenous contamination from ingestion (Hernout *et al.* 2016). Depending on the technique, it can also reveal external accumulation of

elements such as lead, cadmium, and copper on its surface (Rendón-Lugo *et al.* 2017). Trace elements accumulate through both pathways during hair growth, providing a broader temporal window than blood or excreta (Varsha 2013). This integrative nature, combined with non-invasive collection, makes hair a highly recommended matrix for future studies, facilitating long-term monitoring and research on rare or endangered species.

Analyzing different trophic guilds provides valuable information on metal transit through ecosystems. For instance, studies on nectarivores, frugivores, and herbivores elucidate contaminant passage from soil to nectar or leaves (Tataruch and Kierdorf 2003; Kalisińska 2019). Thus, expanding research to include all guilds, particularly understudied omnivores, sanguivores, and nectarivores, is essential for a holistic understanding of contaminant dynamics.

Most reviewed studies employed direct elemental detection techniques, notably spectroscopic analysis, which is rapid but requires meticulous sample preparation (Wiłkomirski 2013). Atomic Absorption Spectrometry (AAS) was the most used analytical method, followed by ICP-MS. The use of the latter has recently increased due to its superior sensitivity and power and multi-element detection capabilities, albeit at higher cost (Gorman and Conway 2005). This trend towards more sensitive

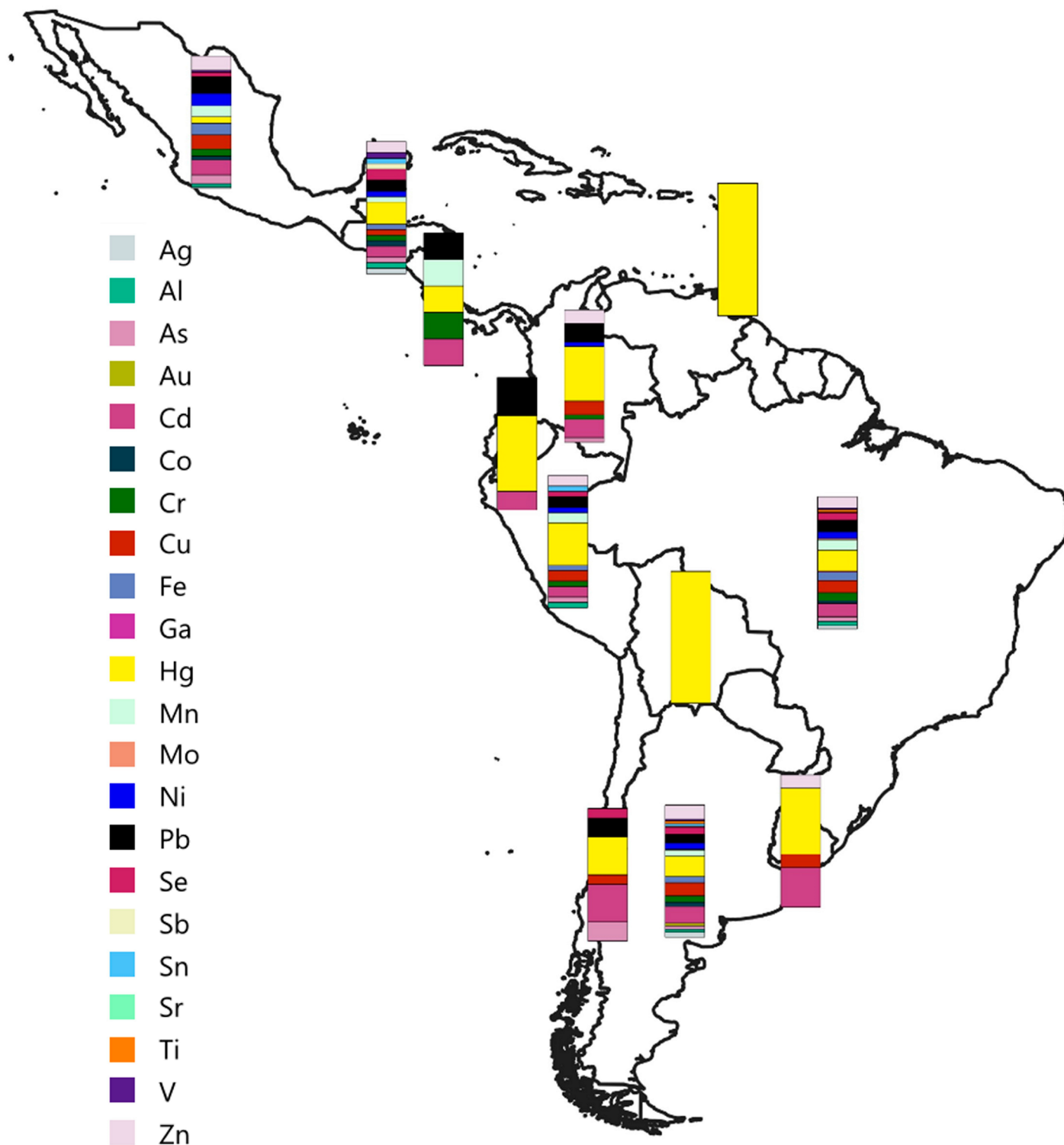


Figure 6. Proportion of trace elements studied in wild mammals in Latin America from 1974 to 2025.

techniques will likely continue, enabling the detection of a wider range of contaminants at lower concentrations and improving risk assessments. Additionally, techniques have diversified to include histochemical damage assessment, behavioral analysis, mathematical modeling, and genotoxicity assays ([Banse-Bueno and Aguayo-Lobo 2020](#); [Fernández-Macías et al. 2020](#); [Hernández-Plata et al. 2020](#)) (Figure 8). This methodological expansion is a positive step, moving beyond mere quantification of

metal concentrations to understanding their biological effects at the individual, population, and ecosystem levels. This opens the possibility for multidisciplinary research lines to address this complex issue.

Most samples originated from natural ecosystems via direct collection (Figure 9). However, trace elements can also be detected in non-perishable matrices such as hair, bone, and teeth ([Racero-Casarrubia et al. 2012](#); [Tovar-Sánchez et al. 2012](#); [Rendón-Lugo et al. 2017](#)). This presents an

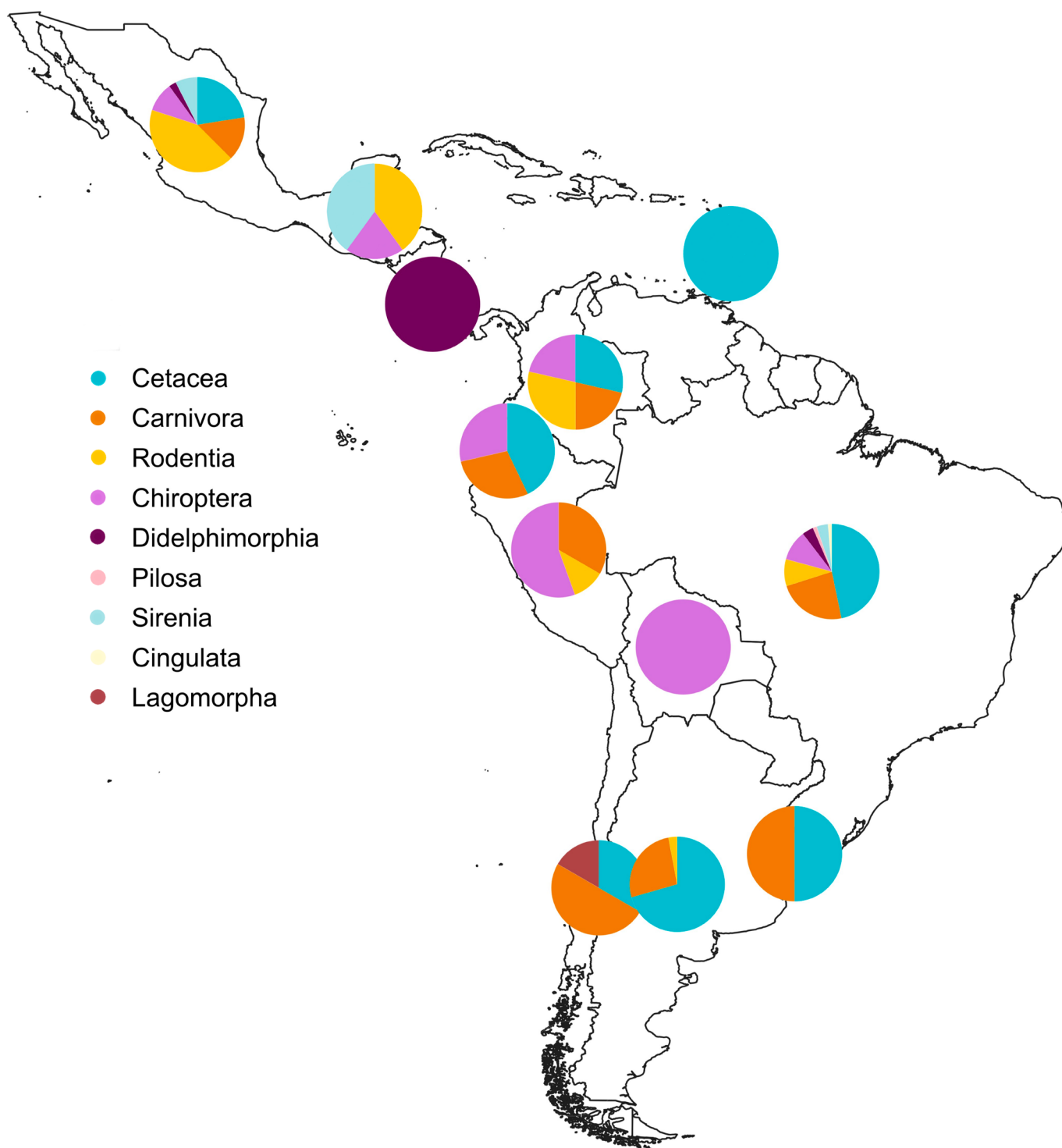


Figure 7. Main mammalian groups used as biomonitors of trace elements in Latin America from 1974 to 2025.

effective opportunity to leverage scientific collections and even paleontological contexts for establishing temporal baselines and historical contamination trends, providing critical context for current levels.

The emergence of studies in urban systems ([Pinzón 2010](#); [Ramos-H et al. 2020](#); [Tripodi et al. 2020](#)) and mining areas ([Tovar-Sánchez et al. 2012](#); [Mussali-Galante et al. 2013](#); [De la Cruz Guarneros 2018](#); [Hernández Plata et al. 2020](#)) is noteworthy. These studies are pivotal as they directly assess

the impact of pollution from human activity hubs, including emerging contaminants from electronic waste or chemical industry byproducts.

Considering these findings, intensified efforts are recommended in the continent's arid and semi-arid zones. These areas have scant information, have undergone intense land-use change, and in many cases have given way to extractive industries—a primary source of metal pollution—whose impact on wildlife remains largely

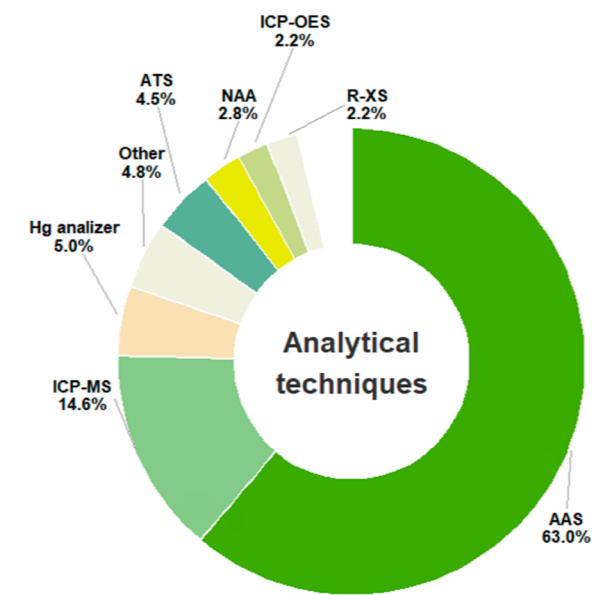


Figure 8. Trace elements assessment techniques in ecotoxicological studies with wild mammals in Latin America between 1974 and 2025.

unknown (Gorman and Conway 2005; De la Cruz-Guarneros *et al.* 2021; Mora-Villa *et al.* 2024). The unique hydrology and ecology of these fragile ecosystems may lead to distinct exposure pathways and heightened vulnerability, warranting immediate investigative attention. Also, the geographical bias toward a few countries implies an overrepresentation of taxonomic groups and ecosystems distributed within those nations, while underestimating contaminant presence in countries with fewer studies. This constitutes a regional concern, as many of the countries with limited published research also face severe socio-environmental problems caused by pollution. Future research can mitigate this imbalance by focusing on underexplored areas and simultaneously, fostering collaborations among countries sharing common pollution issues.

A consensus exists on the need for more studies using diverse matrices and cost-effective techniques. This review underscores that while there is growing interest in

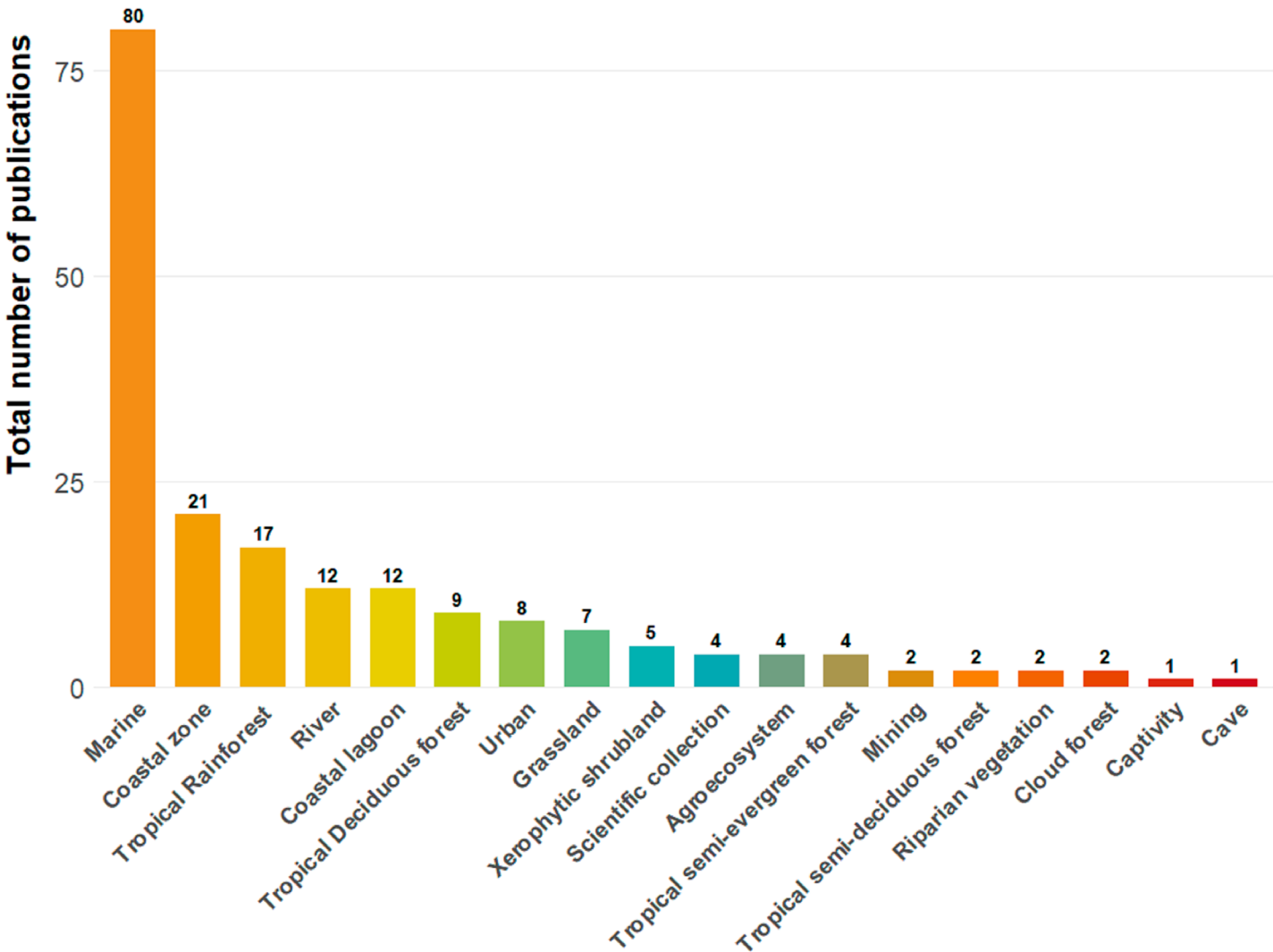


Figure 9. Origin of mammal specimens analyzed in trace elements studies across Latin America between 1974 and 2025.

assessing wildlife health in contaminated ecosystems, the field in this region is still maturing. We also highlight the pressing need to integrate contaminant quantification into environmental management and restoration plans across Latin America, ensuring that conservation strategies are informed by robust ecotoxicological data.

Conclusions

This integrative regional synthesis shows general patterns of metal biomonitoring in wild mammals across Latin America: research efforts are geographically biased, with Brazil, Mexico, and Argentina accounting for over 70% of publications, while Central America, the Caribbean, and arid and semi-arid ecosystems remain largely unknown. Cetaceans and piscivorous species dominate the literature due to phenomena as mercury bioaccumulation, whereas many groups of terrestrial mammals, including large predators, remain mostly understudied. Also, liver and kidney are the most frequently analyzed matrices, but hair offers a non-invasive alternative that can be relevant for endangered species or material from scientific collections.

Given its reliability, AAS is the most widely used analytical technique, though the increasing adoption of ICP-MS reflects a shift toward more sensitive multi-element analyses. On the other hand, the focus on Hg, Pb, and Cd, while justified by their neurotoxicity and links to mining, may overlook synergistic effects of emerging pollutants such as titanium, vanadium, and gallium, requiring broader analytical approaches and multinational collaboration.

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Declaration of artificial intelligence use

The software DeepSeek was used to perform a preliminary translation.

Author contributions

All authors contributed substantially to the design of this study, the analysis and interpretation of the data and the drafting and critical revision of the manuscript. All approved the final version to be published.

Supplementary data

SD1. Studies on toxic metals in mammals from 1974 to 2025 in Latin America.

SD2. Records exceeding international maximum permissible limits (EPA, WHO) for toxic metals in mammals from 1974 to 2025 in Latin America.

Literature cited

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