Utilizing birds as a bioindicator species to monitor potentially toxic elements (PTEs) contamination in an ecosystem

A madarak bioindikátorként történő alkalmazása a potenciálisan toxikus elemek (PTE-k) szennyeződésének nyomon követésére az ökoszisztémákban

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Abstract: Potentially Toxic Elements (PTEs) is a versatile term which includes heavy metals, non-metals and even essential elements, that pose significant environmental and health risks to humans, animals, and plants. Bioindicator species, particularly birds, are valuable tools for monitoring PTEs contamination in ecosystems, offering insights into pollutant levels and their ecological impacts. Birds, as top predators with extensive mobility, absorb contaminants across large areas, making them effective bioindicators in freshwater ecosystems such as lakes, rivers, and wetlands. This study reviews recent research (2014-2024) on the use of birds for biomonitoring of PTEs, focusing on their behavior, feeding habits, and migration patterns, which influence contamination accumulation. Key findings indicate that bird species' diet, residency, and foraging behavior significantly affect PTEs bioaccumulation, with migratory species showing higher metal concentrations. Different sample types, including feathers, blood, and excrement, serve as non-destructive methods for assessing PTEs exposure in birds, with feathers possibly becomes a reliable indicator of metal accumulation in internal tissues. The review emphasizes the importance of selecting appropriate bird species and sample types to enhance the accuracy of environmental contamination assessments and underscores the utility of birds in understanding the broader ecological effects of PTEs pollution.

Keywords*: thematic review, potentially toxic elements (PTEs), bioindicator, birds, heavy metals*

Összefoglalás: A potenciálisan toxikus elemek (PTE-k) egy sokoldalú kifejezés, amely magában foglalja a nehézfémeket, a nem fémeket és akár az esszenciális vegyületeket is, amelyek jelentős környezeti és egészségügyi kockázatot jelentenek az emberekre, állatokra és növényekre. A bioindikátor fajok, különösen a madarak, értékes eszközök a PTE-k szennyeződésének monitorozására az ökoszisztémákban, mivel betekintést nyújtanak a szennyező anyagok szintjeibe és azok ökológiai hatásaiba. A madarak, mint csúcsragadozók, akik széles körű mobilitással rendelkeznek, képesek felhalmozni a szennyező anyagokat nagy területeket bejárva, így hatékony bioindikátorok az édesvízi ökoszisztémákban, mint tavak, folyók és mocsarak. Közleményünkben a madarak PTE-k biomonitoring célú felhasználásával

kapcsolatos legújabb kutatásokat (2014-2024) vizsgálja, kiemelve azokat a tényezőket, amelyek befolyásol(hat)ják a szennyeződés felhalmozódását, így a madarak viselkedését, táplálkozási szokásait és a migrációs mintáikat,. A legfontosabb megállapítások azt mutatják, hogy a madárfajok étrendje, tartózkodási helyük és táplálkozási magatartásuk jelentősen befolyásolják a PTE-k biokumulációját; a migráló fajok alapvetően magasabb fémkoncentrációkat mutatnak. A különböző típusú minták, például tollak, vér és ürülék, nem destruktív módszerekként szolgálnak a madarak PTE-k expozíciójának értékelésére, a tollak pedig megbízható indikátorrá válhatnak a fémek felhalmozódására a belső szövetekben. A tanulmány hangsúlyozza a megfelelő madárfajok és minta típusok kiválasztásának fontosságát a környezeti szennyeződés értékelésének pontosságának növelésében, és kiemeli a madarak hasznosságát a PTE-k szennyezésének szélesebb ökológiai hatásainak megértésében.

***Kulcsszavak**: tematikus áttekintés, potenciálisan toxikus elemek (PTE-k), bioindikátor, madarak, nehézfémek*

1 Introduction

Potentially toxic elements (PTEs) are a broad term used to describe contaminants which include heavy metals with density greater than 5 gcm^{-3} and non-metals. Heavy metals persist in the environment and can cause toxic effects to humans, animals and plants. Essential elements (micronutrients and trace elements) that are bioavailable at high concentration and become toxic are also consider as heavy metals. Whereas, non-metals also has its function in plants and humans at low concentration such as Arsenic (As) and selenium (Se) (Nieder & Benbi, 2024). These contaminants exist naturally in the environment with addition to anthropogenic sources (urbanization, manures, mining, fertilizers and pesticides, vehicle exhaust, coal burning). Once it is bioavailable, organisms at higher trophic level (i.e. birds) absorb these elements from macro-invertebrates and other abiotic elements which subsequently accumulated in their body (Sanchari, 2023).

Bioindicator is a measured sample that is taken from a biological species such as birds to monitor the burden of toxicants in the environment. Instead of studying a large sample from natural ecosystems, a fraction of sample from biological species could access the impact of contaminants of concern in an ecosystem (Egwumah et al., 2017). Typically, birds are an excellent species that could be used to observe metal burden, environmental health and their habitat habilitation (Siddig et al., 2016). Waterbirds are at the top of the food chain and have been shown to be appropriate for monitoring environmental contamination due to their long lifespan and great mobility, which allows them to absorb contaminants across a wide area (Kocagöz et al., 2014).

2 Methods

Relevant articles were scouted from scientific article search engine and database Google Scholar and PubMed. Discrete keywords such as ‘bioindicator species’, ‘birds biomonitoring’ and ‘wetlands contaminants’ were used. Only English articles from the year 2014 to 2024 were considered in this review. The articles that discussed contaminants in freshwater ecosystems which includes lakes, river and wetlands were considered in inclusion criteria while articles on biomonitoring of other organisms were omitted.

40 articles were considered and 21 were selected for this article. References management software (EndNote 20) was utilized to record and systemically review the articles based on

main keywords and assist for in-text citation. Thematic synthesis was conducted when reviewing the articles and main findings were extracted to integrate the theories to draw broader conclusions.

3 Results and Discussion

Bird species are one of the feasible vertebrates to be used as an indicator to measure the metals burden in the environment due to their morphology and physiology characteristics. Indirectly, when measuring the PTEs in birds, there are in-depth information regarding their health such as their dietary deficiency which makes them more prone to metal toxicity (Espín et al., 2024). This is crucial when selecting a specific avian species to study certain elements.

The source and distributions of contaminants could be traced down whether it is a point source or due to the trophic transfer, land use or the transport of contaminants based on the behavior, life history, migration and territory of the studied birds' species (Maznikova et al., 2024). Typically, bio-indicator species were chosen based on existing research, conservation status and their abundance in the study area to facilitate with the research trajectory and cross-referencing with the available information (Siddig et al., 2016).

3.1 Biomonitoring based on bird's ecology

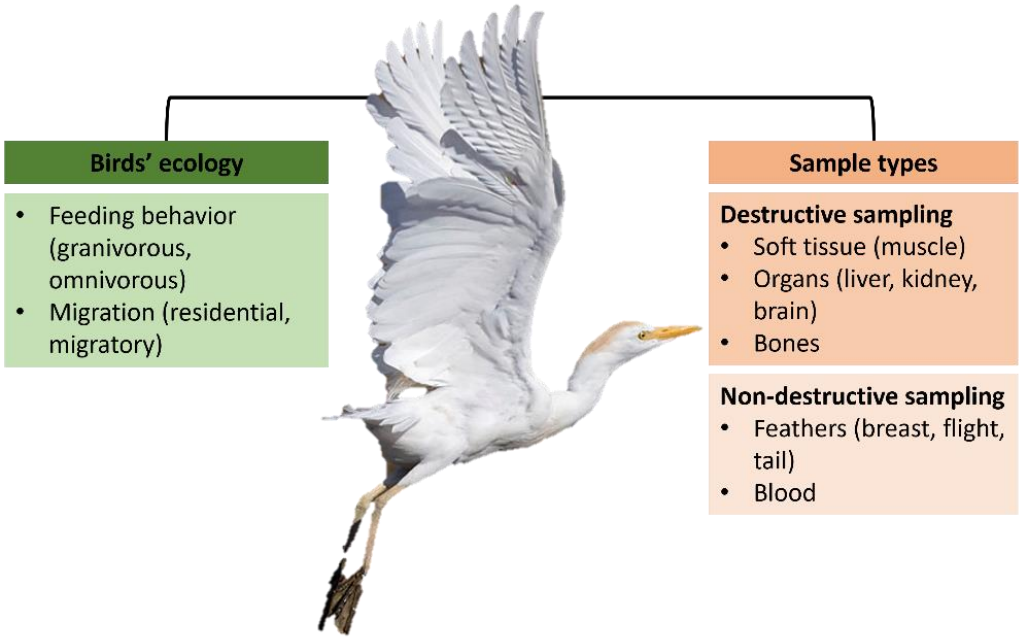

Figure 1 *Factors to consider when selecting bird's species as bioindicator to study PTEs contamination.*

The behavioral ecology and physiology characteristics of birds provide vast information on the fate of contaminations and how it manifested (Figure 1). There are variations between residential and migratory birds, feeding behaviors (granivorous and water birds), its diet and predator (Kocagöz et al., 2014; Samaraweera et al., 2022). Birds residing in the same geographical area potentially retain different concentration of PTEs depending on their residency pattern, diet and feeding behaviors, genetic and physiological characteristics (Khwankitrittikul et al., 2024).

Some birds who feed on invertebrate may retain higher lead (Pb), cadmium (Cd), nickel (Ni) and zinc in their liver and kidney compared to birds feeding on fish and other omnivorous species (Dahmardeh Behrooz & Burger, 2022). One of the many research projects on semi-aquatic birds revealed the residue of PTEs in different tissues. Copper (Cu), Pb, Cd and chromium (Cr) (in order of highest to lowest concentration) were presented in liver and blood of Cattle egret (*Bubulcus ibis*). The feeding behavior of this species on aquatic animals (i.e. fish) suggest that the PTEs except Cr can be transferred from lower to higher trophic level (Zaman et al., 2022). The ability of PTEs to bioaccumulate through trophic transfer could show potential threat in the ecosystems. For example, the concentration of Se increased when compared to prey and the eggs of passerine birds, Dippers (*Cinclus spp*). The passerines had consumed contaminated prey and then passed down during egg formation which proved a presence of threat to the health of local freshwater ecosystems (Maznikova et al., 2024).

In another research to study the effect of gender on PTEs accumulation in waterbirds by using their feathers shown different fate in different species. Gender of *Anas platyrhynchos* affect the accumulation of Pb while gender of *Anas crecca* affect the accumulation of Cu and Zn (Solgi et al., 2020). In contrast, a study on predatory bird in Hungary by using feathers sample shown no significant different of As, Cd, Pb and mercury (Hg) between genders (Grúz et al., 2019). This finding is also supported by a research in Iran where the level of Pb, Zn, nickel (Ni) and Cd are similar in both genders (Dahmardeh Behrooz & Burger, 2022). Although there is contrast in result between gender of birds, perhaps it is crucial to consider the birds species into consideration when drawing a conclusion.

The concentration of PTEs is high in migratory bird species compared to resident or local birds (Solgi et al., 2020). This could indicate that the accumulation in migratory birds happens over an extended period of time through different locations where they are overwintering. Interestingly, short distance migrant may accumulate higher PTEs than long distance migrant (Dahmardeh Behrooz & Burger, 2022). The reason of this disparity is likely due to localized exposure. Short distance migratory birds may spend longer time in high contaminated area while long distance migratory birds spend shorter time during stop-over and possibly avoiding the high contaminated areas. Hence, it is also crucial to consider using bioindicators that represent diverse habitats and foraging habits to determine the relationship between ecology of birds and its ability to accumulate PTEs.

3.2 Different sample types as bioindicator

There are two different sample categories when deciding to study the PTEs burden in birds which are destructive method and non-destructive or non-invasive methods. Commonly, muscles, bones and soft tissues such as liver were obtained for invasive sampling and rather less destructive catch and release methods to obtain feathers, blood and excrement sampling could be implemented.

Feathers can be obtained from the bird by catch and release method. Birds can be trapped using net, and species, gender identification and age estimation can be noted. 10 to 20 chest feathers as well as two secondary flight feathers can be plucked. The samples are then placed in a sealed bags and labelled with name, date and location. It is important to marked the birds before releasing them to avoid redundant sampling and aid in monitoring in the future (Yao et al., 2021). Other organic sample such as blood can be extracted from the bird's jugular vein by using heparinized syringe. Fresh excrement samples are usually taken during handling the bird for sample collection. Fresh sample need to be stored at -20^{o}C until assayed. Internal tissues and organs are retrieved during necropsy. Birds are euthanized by decapitation or shooting after the exercise is approved for ethical purpose by local regulatory body or national agency for research purpose (Berglund, 2018). The wet and dry samples are usually analyzed by

inductively coupled plasma mass spectrometry (ICP-MS) or inductively coupled plasma optical emission spectrometry (ICP-OES).

Feathers sample are a broad term for the sampling category. Researchers could select specifically different feather types such as from the body, wing, tail and breast (Rutkowska et al., 2018). Feathers are the most common non-destructive sampling because they are easy to handle which does not require deep freezing to store prior to the instrumental analysis. Besides, it is also possible to project the concentration of Pb and Cd in internal tissues once the concentration in feathers is determined (Varagiya et al., 2022). This sample type dictates the contamination source of entry in birds itself either through diets or exogenous factors. For example, Hg detected in feathers could come solely from food intake that transfer the metals through digestive tract into the bloodstream which then ended to the formation of keratin in feathers during detoxification. On the other hand, Cd and Pb detected in feathers can be originated from the metals present in the environment which then directly adhere to the keratin of the feathers (Rutkowska et al., 2018). A study conducted in a wildlife and bird sanctuary in India detected the contamination of Cu and Zn in all 11 studied bird species from the feathers sample. From the results, they could pin-point the sources of contamination whether it occurs naturally, manmade or through their diet by using compartments and multivariate analysis (Anbazhagan et al., 2021). Similar study in Pakistan on Cattle egrets (*Bubulcus ibis*) suggested that the bioaccumulation of contamination in their eggs, feathers, prey and sediment were due to their foraging habits (Abdullah et al., 2015).

Alternatively, using bird's feathers as bioindicator is deemed feasible to estimate the concentration of PTEs in other organs and soft tissues by using multiple regression and correlation analysis. For instance, feathers can be used to determine As, Cr and Pb in bone (sternum and femur) and internal organs (heart, liver, kidney) when the concentration is compared between different sample types to concentration in feathers (Khwankitrittikul et al., 2024; Mukhtar et al., 2020). On the other hand, specific tissue or organs sample could be selected to bio-monitor specific PTEs due to the sensitivity of these samples to certain elements. Based on previous studies, liver, feathers and kidney could be used to study Hg while liver, feather and kidney can be used to monitor Cd (Vizuete et al., 2019).

Blood and excrement were less discussed in published literature. However, they can be considered as a non-destructive sample to monitor the PTEs such as As, Cd, Zn, Pb and Cu. Berglund (2018) compare the heavy metal burden in blood and excrement then in then liver. Asymptomatic relationship was present for As, Cd and Pb when compared to liver and blood, excrement and liver and excrement and blood. However, at higher contamination area, using blood may underestimate the actual hazard. Meanwhile, excrement may overestimate the concentration at high exposure. Moreover, there is limited research on the PTEs level in the brain of bird. A study on birds' brain concluded that brain contain significant highest level of PTEs (Zn, Pb, Ni and Cd) than in liver, kidney and muscle (Dahmardeh Behrooz & Burger, 2022).

4 Conclusions

In conclusion, birds serve as an effective bioindicators for monitoring the presence and accumulation of potentially toxic elements (PTEs) in ecosystems. Their diverse ecological roles, behaviors, and mobility make them ideal for assessing environmental contamination over large areas and for extended periods. The study highlights the importance of considering factors such as residency patterns, diet, and migration in understanding how different bird species accumulate PTEs. Various sampling methods, including non-destructive techniques like feather analysis, offer valuable insights into the concentrations of toxic elements without compromising the health of the birds. The findings underscore the need for targeted research using specific bird species and appropriate sample types to improve the accuracy of environmental monitoring and better understand the impacts of PTEs pollution. By utilizing birds as bioindicators, we can gain crucial knowledge to inform conservation efforts and mitigate the environmental and health risks associated with PTEs contamination.

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