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Bioaccumulation of Trace Metals (Zn, Cd, Cu, Pb, and Fe) in *Boops boops* (Walbaum, 1792) from the Algerian West Coast: Human Health Risk Assessment

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ABSTRACT

Despite its prevalence in the Algerian fishery sector, limited research has examined metal contamination in *Boops boops* (L., 1758), a widely consumed sparid species along the Algerian coast. This study quantified five potentially hazardous metals, zinc (Zn), cadmium (Cd), copper (Cu), lead (Pb), and iron (Fe), in the gonads and gills of *B. boops*, given their bioaccumulation potential in aquatic ecosystems. Between January and December 2023, monthly samples were collected from four major fishing ports from the Algerian west coast. Atomic absorption spectrophotometry was used to analyze seasonal and sex-based variations in metal concentrations. Findings indicate that males accumulate higher levels of zinc in their gonads, whereas females show greater bioaccumulation of lead, copper, iron, and cadmium. In the gills, males exhibit higher concentrations of heavy metals than females. Seasonal variations reveal increased contamination of gills by Cd, Cu, and Pb in winter, while gonads contain higher levels of Zn, Pb, and Cu during the same period. Nevertheless, metal concentrations in *B. boops* from the study area are generally lower than those reported in other Mediterranean regions. This study evaluated the estimated daily intake (EDI), weekly intake (EWI), and target hazard quotient (THQ). Copper concentrations were low (EDI: 0.038–0.051mg/ kg), whereas iron levels were comparatively higher (EDI: 1.468–2.932mg/ kg), particularly in children. Lead exposure exceeded recommended intake levels for children (EDI: 0.093–0.113mg/ kg), posing potential health risks. Zinc exhibited the highest EDI values among the analyzed metals, especially for children (EDI: 2.085–2.932mg/ kg). THQ analysis showed that all values remained below 1, indicating no immediate health hazard; however, cadmium and lead presented relatively high THQ values in female children (THQ: 0.17 and 0.123, respectively) All samples showed metal pollution index (MPI) values <1, confirming minimal contamination. These findings highlight Pb as a critical risk for children, despite overall low MPI, underscoring the need for targeted dietary intervention and ongoing health risk assessments.

INTRODUCTION

Boops boops is a prominent component of the Mediterranean diet. The selection of this pelagic species is based on its socio-economic significance and prevalence along the Algerian coastline **(Mezedjri *et al.*, 2013)**. Geographically, *B. boops* is found throughout the Mediterranean Sea, the Black Sea, and the Eastern Atlantic Ocean **(Handjar *et al.*, 2022)**. *Boops boops* is a gregarious or demersal semipelagic species that can inhabit various substrates in shelf or coastal pelagic zones. It typically resides at depths between 0 and 500 meters, with a higher frequency at around 150 meters. This species exhibits nocturnal behavior, rising to the surface during the night **(Abecasis *et al.*, 2008)**. The ability of *B. boops* to move freely and to absorb heavy metals through multiple pathways, such as consuming suspended particles in water and their prey, makes it a key species for studies on heavy metal contamination.

The Algerian west coast is subject to considerable stress from toxic contaminants, both anthropogenic and industrial **(Hassani & Kerfouf, 2015; Mehtougui *et al.*, 2018; Benallal *et al.*, 2020)**. Moreover, it experiences significant inputs of anthropogenic pollutants **(Dilem *et al.*, 2014; Mehtougui *et al.*, 2015; Kerfouf *et al.*, 2022)**. Research in this area is limited, with most studies focusing on heavy metal contamination in sediments and plants. The bioaccumulation of trace metals in all aquatic organisms results from their concentration in water and aquatic microorganisms **(Can *et al.*, 2012)**.

The presence of heavy metals in fish is influenced by various factors, including habitat, the chemical composition of water, environmental variables, and the biological status of the fish **(Copat *et al.*, 2012)**. Metal pollution represents a major human-induced disruption affecting marine organisms in coastal and estuarine ecosystems **(Kalakhi *et al.*, 2023)**. This study aimed to examine the seasonal fluctuations in the concentrations of metallic elements (Zn, Cd, Cu, Pb, and Fe) in the marine fish species *B. boops* (Walbaum, 1792), commonly found along the Algerian west coast.

This study focused on the analysis of trace metals (Zn, Cd, Cu, Pb, and Fe) in the gonads and gills of *B. boops*, along with an evaluation of potential human health risks. Key aspects include the estimated weekly intake of metals (EWI), target hazard quotients (THQ), and the mean pollution index (MPI) calculated by taking the geometric mean of the elements detected in fish. It provides the first detailed examination of metal contamination in *B. boops*, a widely consumed sparid species along the Algerian coastline, presenting critical findings for public health. By highlighting that metal accumulation levels are within international health standards, our research offers valuable insights for consumer safety and underscores the commercial significance of *B. boops* in Algerian fishery markets. Additionally, the study elucidated seasonal and gender-based variations in contamination, enhancing our understanding of metal accumulation and biomagnification effects in marine ecosystems.

MATERIALS AND METHODS

1. Sampling and chemical analyses

Samples were collected monthly from commercial fisheries located in Béni Saf, Bouzedjar, Oran, and Mostaganem, spanning from January 2023 to December 2023 along the western coast of Algeria (Fig. 1). A total of 460 fish were collected, comprising 232 females, 131 males, and 97 individuals of indeterminate sex. The gonads and gills were selected for the analysis of essential metals and for the macroscopic assessment of sex due to their importance in the investigation. To assess metal concentrations, the method outlined by **Amiard (1987)** was employed.

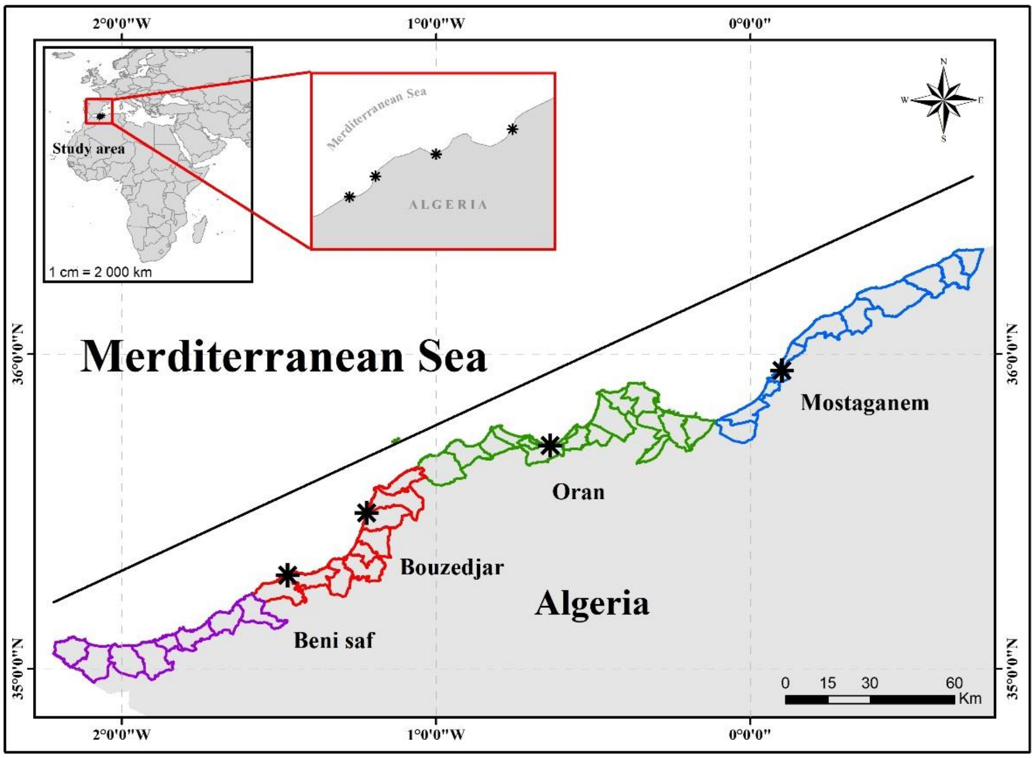

Fig. 1. Geographical location of sampling sites

2. Health risk estimation

The highest eligible element concentrations in fish are determined based on national and international food standards **(FAO/WHO, 1984, 1989; WHO, 1995)**. The analysis of metal absorption in each fish was conducted utilizing the metal pollution index (MPI), which was calculated based on the equation described below **(Usero *et al.*, 1997)**. The mean pollution index (MPI) was calculated using the following formula:

$MPI = (C1 \times C2 \times \cdots \times Cn)^{1/n}$ (1); Cn: the average concentration of trace metals (n), mg kg^{-1} Fresh weight.

If the total index is more than 1, the trace metal concentrations are considered high and the environment can be considered "polluted" **(Teodorovic *et al.*, 2000)**. By determining the estimated daily intake (EDI) and estimated weekly intake (EWI) of pollutants present in fish muscle, the damage to human health associated with seafood consumption was evaluated **(USEPA, 2014)**:

$EDI = {FIR \times C}/{BW}$ (2); FIR: the fish ingestion rate (g/person/day); C: the metal concentration in samples mg/kg, fresh weight (FW).

$EWI = {(Cm \times IRw)}/{BW}$ (3); Cm: the element concentration in seafood (μg g^{-1}); IRw: the weekly ingestion rate (g week-1).

A measure of the risk of non-carcinogenic consequences, the target hazard quotient (THQ) is the ratio of exposure to the reference dose (RfD) **(USEPA, 2014)**:

$THQ = [{(EF \times ED \times FIR \times C}/{RfD \times BW \times AT)}] \times 10^{-3}$ (4); EF: the exposure frequency (365 days $year^{-1}$ for people who eat fish seven times a week; 156 days $year^{-1}$ for people who eat fish three times a week); ED: the exposure duration (adults 70 years, children 7 years), C: the metal concentration in seafood (μg g^{-1}); RfD: the oral reference dose for Fe, Cu, Zn, Cd and Pb (USEPA, 2014); BW: the body weight: 70 and 32kg for adults and children, respectively **(USEPA, 2014)**; AT: the average time for non-carcinogens (356 days $year^{-1}$ x ED).

RESULTS

Based on the fresh weight (FW) of the gonads and gills, which is expressed as mg/kg FW, the average concentrations were calculated (Fig. 2).

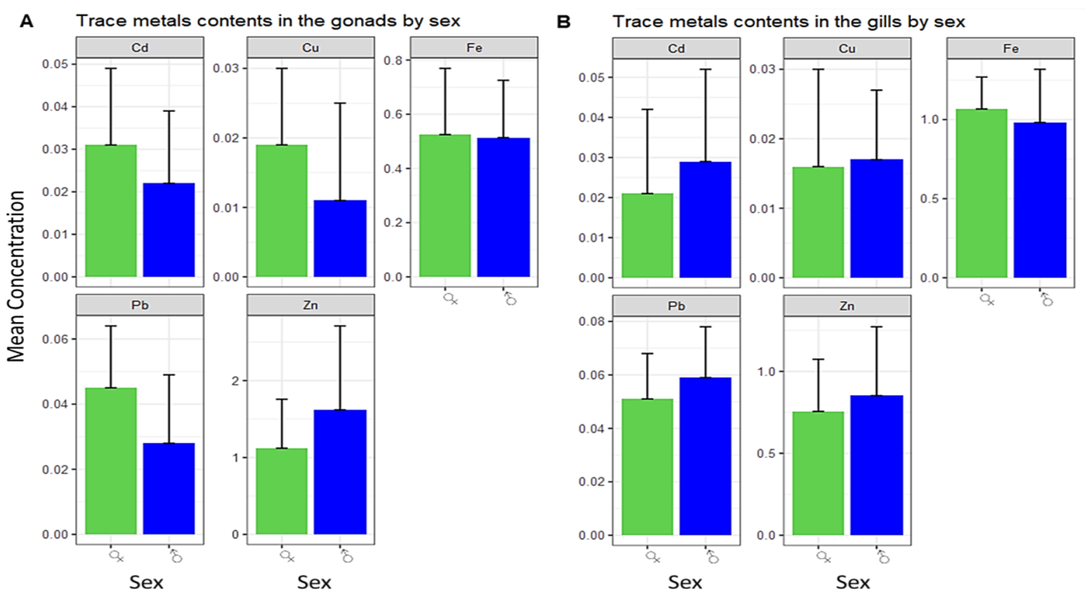

Fig. 2. Mean and standard deviation of heavy metals contents in the gonads and gills by sex

1. Variations by organs and sex

Cadmium accumulation was detected in the gonads and gills of male individuals (0.022±0.017mg/ kg FW; 0.029±0.023mg/ kg.FW) in contrast to female gonads and gills (0.031±0.018; 0.021±0.021mg/ kg.FW). The level of Cu in the gonads reveal that females (0.019±0.011mg/ kg.FW) show higher levels of contamination compared to males (0.011±0.014mg/ kg.FW). The proportions of copper in the gills are similar across sexes, recorded at 0.017±0.010mg/ kg.FW for males and 0.016±0.014mg/ kg.FW for females.

Iron concentrations in the gonads of both sexes are comparable, measuring 0.525±0.244mg/ kg.FW for males and 0.514±0.211mg/ kg.FW for females. In the gills, female concentrations are marginally elevated at 1.067±0.202mg/ kg.FW. Lead concentrations in the gonads are greater in females (0.045±0.019mg/ kg.FW) compared to males (0.028±0.021mg/ kg.FW). The concentrations in the gills display slight variation between the sexes, recorded as 0.051±0.017 and 0.059±0.019mg/ kg.FW.

Zinc concentrations in male gonads are higher (1.62±1.091mg/ kg.FW) compared to females (1.121±0.637mg/ kg.FW). The accumulation of this metal is greater in male gills (0.852±0.420mg/ kg.FW) versus females (0.756±0.318mg/ kg.FW). The two predominant factors represented 96.6% of the throughout variation. Gonads displayed increased concentrations of Pb (lead), Cu (copper), and Fe (iron), while gills demonstrated higher levels of Zn (zinc) and Cd (cadmium). Furthermore, within the gonads, differentiation occurs based on sex, with females accumulating higher levels of cadmium and males accumulating more zinc (Fig. 3).

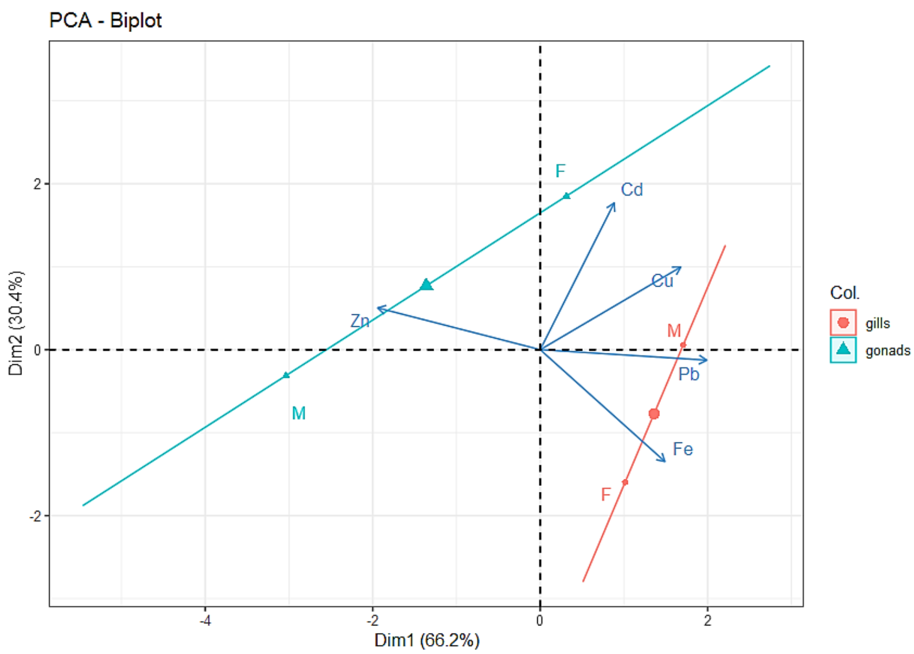

Fig. 3. Principal component analysis (PCA) of heavy metals contents in the gonads and gills by sex

2. Seasonal variations

The samples indicate seasonal variations in heavy metal content (Fig. 4). Cadmium concentrations are low in autumn, measuring 0.014 ± 0.003mg/ kg.FW in gonads and 0.009 ± 0.004mg/ kg.FW in gills. In spring, copper concentrations in the gonads are recorded at 0.018 ± 0.008mg/ kg.FW, while in the gills, they are observed at 0.016 ± 0.005mg/ kg.FW. Iron content in the gills is highest in springer at 1.093±0.339mg/ kg.FW and in autumn at 1.047±0.482mg/ kg.FW. The values for lead are nearly identical across seasons for the two organs, except in autumn, when the values recorded are zero. The findings indicate that Zn concentrations are greatest in winter (2.018±1.014mg/ kg.FW) and spring (1.567±0.796mg/ kg.FW) within the gonads. The two principal components explain 69.3% of the total variation and categorize the seasons into three distinct clusters. Autumn exhibited low concentrations of lead and cadmium, whereas winter displayed elevated levels of zinc, copper, lead, and cadmium. Furthermore, spring exhibited elevated concentrations of iron (Fig. 5).

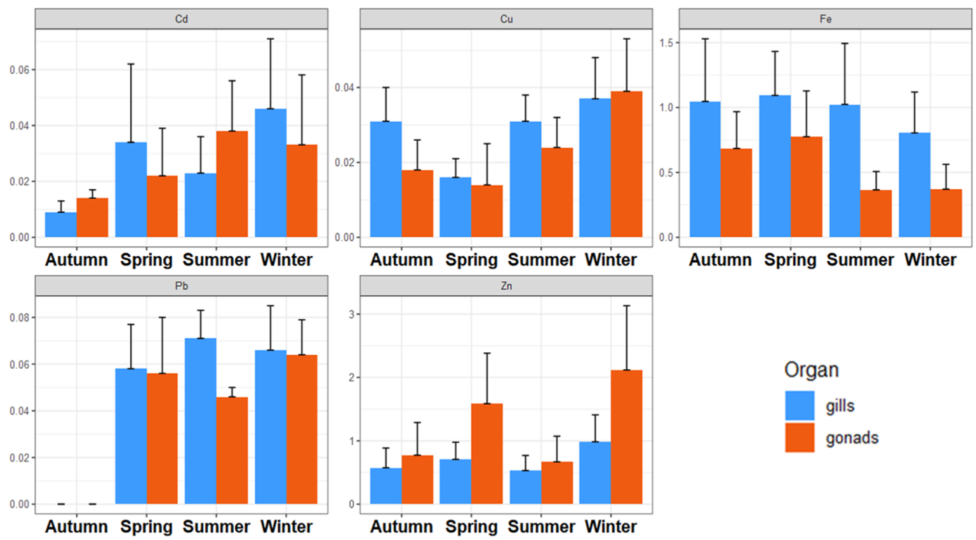

Fig. 4. Mean and standard deviation of heavy metals contents in the gonads and gills by season

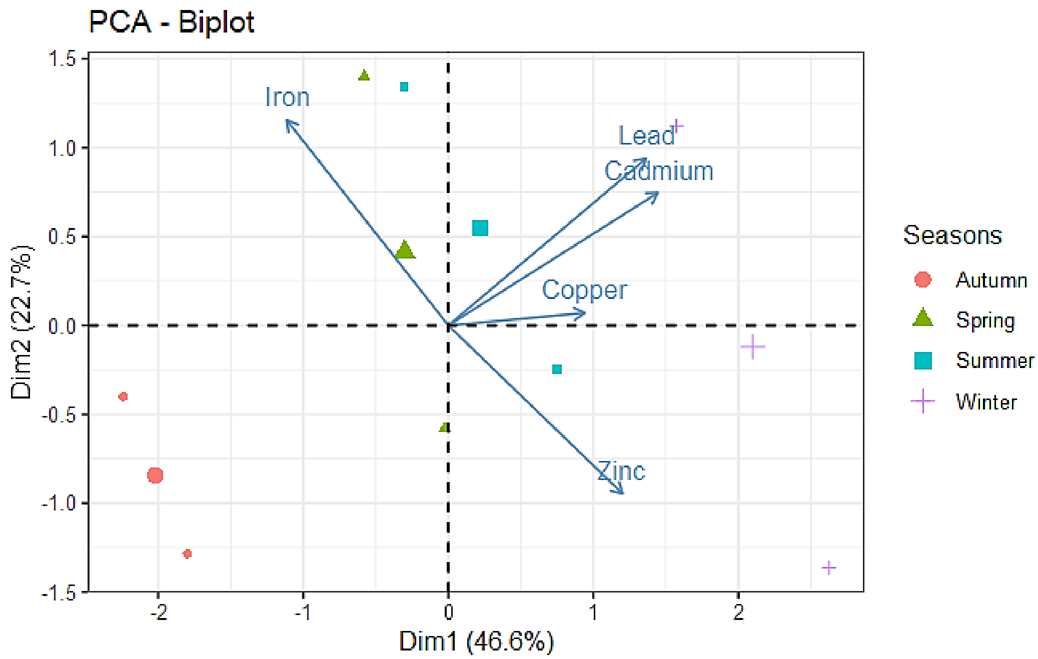

Fig. 5. Principal component analysis (PCA) of heavy metals contents in the gonads and gills by season

The comparative analysis of average heavy metal concentrations in both sexes reveals that females accumulate greater levels of Pb, Cu, Fe, and cadmium in their gonads compared to males. The concentrations of Zinc determined at the gonadal level suggest that males reveal a higher susceptibility compared to females. In the gills, all examined heavy metals display higher levels of bioaccumulation in males as opposed to females.

3. Health risk assessment

The analysis of the estimated daily intake (EDI) and weekly intake (EWI) of heavy metals (Cd, Cu, Fe, Pb, Zn) in *B. boops* from the Algeria coast reveals significant findings regarding the dietary exposure of adults and children in the Algerian west coast. These results provide critical insights into the potential health risks associated with seafood consumption in the region (Table 1).

Table 1. The estimated daily (EDI) and weekly (EWI) intakes (mg/kg FW) for *Boops boops (male and female)* from Algeria Sea, consumed by human adults (a) and children(c) in the Algerian west coast

Heavy metals	♂				♀				DW
(mg.g-1/Fw)	EDI a	EWI a	EDI c	EWI c	EDI a	EWI a	EDI c	EWI c	MTDI
Cd[a]	0,077	0,0156	0,066	0,020	0,078	0,0156	0,067	0,020	0.05

Cu[b]	0,044	0,008	0,038	0,011	0,051	0,010	0,044	0,013	4.50
Fe[b]	1,706	0,341	1,468	0,448	1,744	0,349	1,500	0,458	100
Pb[c]	0,109	0,021	0,093	0,028	0,113	0,022	0,097	0,029	0.20
Zn[b]	3,408	0,682	2,932	0,896	2,428	0,485	2,085	0,637	30

MTDI: Maximum tolerable daily intake according to international standards (a: **FAO/WHO (2010)**; b: **FAO/WHO (2007)**; c: **FAO/WHO (2004)**.

The calculated THQ values (Table 2) assess the non-carcinogenic health risks from consuming *B. boops* from the Algerian west coast. THQ values below 1 are generally considered safe, indicating no significant health risks. However, variations among metals and consumer groups (adults vs. children) require careful interpretation.

The THQ (Table 2) for Cd shows relatively high values, with children reaching a THQ of 0.17 (for females) and 0.066 (for malesTHQ values for Pb are noteworthy, particularly in female children, reaching 0.123.

Zn has the lowest THQ values (0.009-0.011), well below the safety threshold, indicating negligible health risks. The cumulative hazard index (THQs T) for children (0.126 for males, 0.319 for females) exceeds that of adults (0.147 for males, 0.17 for females). This finding underscores the greater susceptibility of children to metal exposure due to their lower body weight and higher consumption rates relative to body size.

Table 2. The Estimated Target Hazard Quotients (THQ) for metals caused by consuming *Boops boops* (male and female) from Algeria Sea, consumed by human adults (a) and children(c) in the Algerian west coast.

	♂		♀	
Heavy metals	THQs a	THQs c	THQs a	THQs c
Cd	0,077	0,066	0,090	0,170
Cu	0,001	0,0009	0,001	0,002
Fe	0,002	0,002	0,002	0,005
Pb	0,054	0,046	0,065	0,123
Zn	0,011	0,009	0,009	0,017
THQs T	0,147	0,126	0,170	0,319

DISCUSSION

The results of this study provide a comprehensive assessment of heavy metal exposure through the consumption of *Boops boops* from the western Algerian coast, with specific emphasis on dietary risks for both adults and children. Copper (Cu) levels were found to be consistently low across all groups, with EDI values ranging from 0.038 to 0.051mg/ kg body weight/day. These values remain well below internationally established safety limits and are consistent with previous studies conducted along other Mediterranean coasts, which have reported minimal copper contamination in marine species **(Hamed *et al.*, 2021)**. This suggests that copper exposure from *B. boops* in this region does not pose a health concern.

Iron (Fe), while essential for numerous physiological processes, was present at relatively high concentrations. EDI values ranged from 1.468 to 1.744mg/ kg in adults and 1.500 to 2.932mg/ kg in children. Despite these elevated levels, they remain within tolerable upper intake levels established by dietary reference authorities. Importantly, such intake may help address iron deficiency, which is prevalent in North African populations, particularly among children and women of reproductive age **(Bouhadjera *et al.*, 2022)**. Nevertheless, chronic overconsumption may carry the risk of oxidative stress or iron overload in susceptible individuals.

Lead (Pb) exposure emerged as a critical concern. EDI values (0.093–0.113mg/ kg) exceeded tolerable intake thresholds for children as set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and other regulatory bodies. Lead is a potent neurotoxin, especially harmful to children due to its effects on cognitive development and behavior. The elevated THQ values for Pb, particularly in female children (0.123), reinforce this concern and point to a potentially vulnerable demographic group in the study area.

Zinc (Zn) displayed the highest EDI levels among all metals, with children experiencing greater exposure (2.085–2.932mg/ kg) than adults (2.428–3.408mg/ kg). While zinc is a vital micronutrient involved in immune function, enzyme activity, and growth, excessive intake can interfere with the absorption and metabolism of other trace elements, especially copper. The relatively high Zn values observed here, although not immediately hazardous, suggest the need for nutritional monitoring to prevent long-term imbalances **(Bouhadjera *et al.*, 2022)**.

Cadmium (Cd), though present at lower concentrations, showed significant THQ values in children (0.17 in females and 0.066 in males). Cadmium is known for its bioaccumulative properties and long biological half-life, particularly in the kidneys, raising concerns about chronic low-level exposure. These findings align with studies from other parts of the Mediterranean, where cadmium bioaccumulation in fish has been linked to agricultural runoff and industrial discharge **(Papagiannis *et al.*, 2023)**.

Overall, although the THQ values for all metals remained below the threshold of 1, indicating no immediate non-carcinogenic health risk, the elevated intake levels of lead, zinc, and cadmium—especially in children—highlight the need for continued monitoring. Public health strategies should consider issuing consumption advisories for sensitive populations and enforcing stricter pollution control measures along the Algerian coast.

Species that share the same habitat in the aquatic environment are affected by the pollution they are exposed to, and this pollution can accumulate in varying amounts in each species **(Türk Çulha *et al.*, 2022)**. The results of this study reveal significant differences in trace metal concentrations in the gonads of *B. boops* between males and females, which can be attributed to their distinct physiological and reproductive roles. Zinc (Zn) levels were notably higher in males than in females, likely due to its critical role in spermatogenesis and antioxidant defense, which are essential for male fertility **(Gautam & Chaube, 2018)**. In contrast, lead (Pb) concentrations were slightly elevated in females compared to males, possibly because of differences in bioaccumulation or hormonal regulation during oogenesis, although its toxicity may impair ovarian functions **(Atli & Canli, 2011)**. Copper (Cu), which is vital for vitellogenesis and egg development, was also found to be higher in females than in males, highlighting its importance in reproductive processes **(Canli & Atli, 2003)**. Similarly, cadmium (Cd), a toxic metal known to disrupt hormonal balance, exhibited higher levels in females than in males, potentially posing risks to ovarian health **(Monteiro *et al.*, 2009)**. Finally, iron (Fe) concentrations were slightly greater in males than in females, reflecting the higher metabolic demands of the testes required for spermatogenesis **(Kalay *et al.*, 1999)**. These findings underscore the physiological differences between the sexes and the potential risks posed by toxic metal exposure, emphasizing the need for continued monitoring of marine ecosystems.

The comparison of trace metal concentrations in the gills of *B. boops* revealed notable differences between sexes, highlighting the physiological and ecological implications of metal accumulation in fish. While males exhibited slightly higher mean concentrations of zinc and lead compared to females, as indicated by Zn (0.852 ± 0.420 mg/kg in males vs. 0.756 ± 0.318mg/ kg in females) and Pb (0.059 ± 0.019mg/ kg in males vs. 0.051 ± 0.017mg/ kg in females), this discrepancy may be influenced by differences in metabolic rates, gill surface area, and hormonal regulation **(Wang *et al.*, 2022)**.

Furthermore, iron concentrations were more pronounced in males (1.067 ± 0.202mg/ kg), suggesting that their increased oxygen demands, often linked to higher activity levels, could facilitate greater iron uptake from the aquatic environment. On the other hand, the negligible cadmium levels detected in both sexes align with previous research indicating that cadmium tends to accumulate more in internal organs than in gills, particularly under low environmental exposure. These findings are consistent with recent studies that demonstrate sex-specific variations in trace metal bioaccumulation, often mediated by hormonal differences and reproductive cycles **(Samantara *et al.*, 2023)**. Consequently, these results emphasize the importance of considering sex-based physiological differences in ecotoxicological assessments and underscore the role of environmental factors, such as pollution levels, in shaping trace metal uptake patterns **(Wang *et al.*, 2022)**.

Essentially, females demonstrate higher infection rates than males. This distinction may be attributed to their migration to contaminated coastal regions during reproduction, which may explain the elevated contamination levels with heavy metals from various sources **(Soykan *et al.*, 2015)**. This is likely attributable to the process of accumulating nutrient reserves during vitellogenesis **(Mortet, 1989)**. Nevertheless, the heavy metal concentrations in *B. boops* examined, in relation to the maximum allowable doses (M.A.D), suggest a product that is somewhat contaminated, potentially reflecting the water quality along the Algerian west coast **(I.A.E.A, 2003)**.

On the Algerian coast, in particular, very few studies have investigated metal contamination in the *B. boops* species. Most research has focused on diet diversity **(Derbal & Kara, 2008)**, sexuality, age and growth **(Amira *et al.*, 2019)**, and stock status **(Ider *et al.*, 2017; Boubaiou *et al.*, 2018; Dehal *et al.*, 2019; Handjar *et al.*, 2022)**. Comparable findings have been reported for species prevalent along the Algerian coast, including *Sardina pilchardus* **(Mehouel *et al.*, 2015; Ouabdesselam *et al.*, 2017, 2020; Hamida *et al.*, 2018; Kalakhi *et al.*, 2023)**.

Other research has examined the amount of organochlorine pesticides (OCPs) in the muscles and gills of *B. boops* harvested in the Bay of Oran **(Belhabib *et al.*, 2023)**.

A study focused on metal contamination of *B. boops* in the Bay of Antalya, Turkey, found Fe to be the most abundant metal in tissues, while Cd was the least abundant across all seasons. Muscle and gill tissues exhibited the lowest concentrations of heavy metals, which varied seasonally, peaking in the spring. Both positive and negative relationships were found between metal levels and fish size **(Tekyn-Özan, 2014)**.

Another study discovered heavy metal contamination in organs (kidneys, muscles, gills, and gonads) of *B. boops* in the marine area of the eastern coast of Milazzo, with detectable levels of arsenic, cadmium, chromium, copper, manganese, lead, and zinc. These concentrations were found at or near regulatory limits **(Alesci *et al.*, 2022)**.

The elevated levels of Zn and Pb, especially in children's dietary exposure, call for urgent attention to mitigate potential health risks. These results underscore the need for stricter environmental policies and consistent monitoring of heavy metal contamination in Mediterranean seafood. They align with findings from similar coastal regions, where fish frequently show elevated metal levels due to anthropogenic activity **(Hamed *et al.*, 2021)**.

Elevated lead exposure is associated with serious health risks, including developmental impairments in children. Similar contamination patterns have been observed in seafood from other Mediterranean regions **(Hamed *et al.*, 2021)**.

THQ values are higher than those reported in studies from Tunisia and Greece, where cadmium levels in fish were associated with lower health risks **(Ben Salem *et al.*, 2023; Papagiannis *et al.*, 2023)**. Elevated THQs observed in Algeria may reflect local anthropogenic sources, such as agricultural runoff or industrial discharge. Comparatively, studies from the Adriatic and Aegean seas report similar or slightly lower Pb health risk quotients in *B. boops* populations **(Rossi *et al.*, 2023b)**. This highlights Pb as a consistent pollutant across the Mediterranean, potentially originating from shared sources like atmospheric deposition or maritime activities. Tunisian studies on *B. boops* similarly found Zn levels to pose minimal health risks **(Ben Salem *et al.*, 2023)**. Low THQ values for Zn across Mediterranean studies reflect its relatively low toxicity.
Comparative research from the Mediterranean indicates slightly lower cumulative THQ values, emphasizing the need for localized pollution mitigation strategies **(Rossi *et al.*, 2023b)**.

THQ values from the Algerian *Boops boops* dataset are broadly consistent with findings from other Mediterranean regions though they show slightly elevated levels for Cd and Pb, indicating region-specific pollution factors. Zinc remains consistently low-risk across studies. These differences highlight the importance of local monitoring and source identification to reduce consumer risk. While overall THQs are below the critical threshold of 1, elevated values for Cd and Pb—particularly in children—signal the need for targeted actions.

If the metal pollution index (MPI) is greater than 1, it indicates contamination, while a value below 1 suggests no significant contamination **(Ahmed *et al.*, 2018)**. In this study, all fish samples exhibited MPI values well below 1, indicating an absence of heavy metal contamination. The highest MPI was recorded in *F. grey mullet* at 0.009, consistent with findings from other environmental assessments along the Algerian coast **(Boutiba *et al.*, 2020; Zghdoudi *et al.*, 2024)**.

CONCLUSION

Monitoring metal levels in *Boops boops* confirms the presence of these pollutants along the western Algerian coast. Consequently, the bogue examined in this study appears to be moderately contaminated, potentially reflecting the water quality of the study area. The concentrations of heavy metals identified are comparable to those reported in other contaminated regions of the Mediterranean Sea. Notably, metal concentrations varied with the sampling season, showing a significant increase during winter. This seasonal fluctuation may be influenced by physiological weight changes associated with reproductive cycles, as well as by environmental stressors present during this period.

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