# CORRELATION OF ELEMENT RECORDS IN ARAGONITIC BIVALVE SHELLS OF *CERATODERMA* AS ENVIRONMENTAL PROXIES

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**KEYWORDS**: mineral, toxicity, aquatic organism, sea, correlation.

**ABSTRACT**

The correlation of 60 elements recorded in aragonitic bivalve shells of *Ceratoderma* was tested to identify the trends of their availability in coastal areas of the southwest Caspian Sea in order to more efficiently assess them as a proxy of pollution. An inductively coupled plasma mass spectrometer (ICP-MS) (Agilent 8900-Agilent Technologies, Palo Alto, CA, USA) was used for their quantification. A multi-variate cluster test was used to check the similarity of the elements in the clade membership. The results of this study show highly significant positive and negative correlations among the elements in aragonitic bivalve shells of *Ceratoderma* as a bio-indicator part of an aquatic organism. This would be helpful for saving time and cost especially when utilized as environmental proxies.

**RÉSUMÉ**: Corrélation des enregistrements d’éléments dans les coquilles de bivalves aragonitiques de *Ceratoderma* en tant que proxys environnementaux.

La corrélation d’enregistrements de 60 éléments dans les coquilles de bivalves aragonitiques de *Ceratoderma* a été testée pour trouver la relation et les tendances de leur disponibilité dans les zones côtières du sud-ouest de la mer Caspienne afin de trouver leur relation pour les évaluer plus rapidement comme indicateur de pollution. Un spectromètre de masse à plasma à couplage inductif (ICP-MS) (Agilent 8900-Agilent Technologies, Palo Alto, Californie, États-Unis) a été utilisé pour leur quantification. Un test de cluster multivarié a été utilisé pour vérifier la similarité des éléments appartenant au clade. Les résultats de cette étude montrent des corrélations positives et négatives significatives élevées entre les éléments des coquilles de bivalves aragonitiques de *Ceratoderma* en tant que bio-indicateur d’un organisme aquatique, ce qui serait utile pour économiser du temps et des coûts, en particulier lorsqu’il est utilisé comme proxy environnemental.

**REZUMAT**: Corelarea înregistrărilor elementelor în scoicile aragonitice ale bivalvelor de *Ceratoderma* ca proxi-uri de mediu.

Corelația înregistrărilor celor 60 de elemente în cochiliile aragonitice ale bivalvelor de *Ceratoderma* a fost testată pentru a găsi relația și tendințele disponibilității lor în zonele de coastă din sud-vestul Mării Caspice, pentru identificarea relației lor pentru a le evalua mai repede ca proxi ale poluării. Pentru cuantificarea lor a fost utilizat un spectrometru de masă cu plasmă cuplat inductiv (ICP-MS) (Agilent 8900-Agilent Technologies, Palo Alto, CA, SUA). Un test cluster multivariat a fost folosit pentru a verifica similitudinea elementelor din componența cladei. Rezultatele acestui studiu arată corelații pozitive și negative semnificative între elementele din cochiliile de bivalve aragonitice de *Ceratoderma* ca parte bio-indicator a unui organism acvatic, ceea ce ar fi util pentru economisirea timpului și a costurilor, mai ales atunci când sunt utilizate ca proxi-uri de mediu.

## INTRODUCTION

Bivalves as well as other marine invertebrates can acquire trace elements from the surrounding water and substrate (Ghosn et al., 2020). These species can serve as bioindicators to estimate trace element availability in various locations by accumulating the contaminants in a sedentary manner that does not result in death Khan et al., 2022). All these elements might come from environment through water, substrate, or food (Ghosn et al., 2020). To be utilized as a bioindicator, all species must have the same elemental content as the surrounding marine environment, specifically the water, across all locations and circumstances in the research area (Lomartire et al., 2022). The exploration of element correlation in shells of bivalves has gained increasing attention in recent years (Nour, 2020). Researchers have focused on understanding how different elements interact and how they are incorporated into the shell structure of bivalves, with the goal of elucidating both the environmental conditions and biological processes that influence shell formation (Clark et al., 2020).

Previous studies have shown a wide range of elements existing in different bivalve shells, including calcium, magnesium, strontium, and various trace metals (Piwoni-Piórewicz et al., 2021). The correlation between all these elements can provide insights into the history of a bivalve's environment, such as temperature variations, salinity levels, and pollution exposure (Zhao et al., 2020). Although factors such as genetics and physiological processes influence certain characteristics of bivalve shells, external environmental factors also affect the composition and structure of the shell (Clark et al., 2020). Furthermore, significant correlations between specific elements and shell characteristics were identifies and observed, shedding light on the biomineralization process in bivalves (Wang et al., 2022; Dai et al., 2020).

This study attempts to look at the correlation and dispersion of certain elements along the coastal area of the southwest Caspian Sea using the aragonitic bivalve shells of *Ceratoderma*.

## MATERIAL AND METHODS

Sampling of *Ceratoderma* bivalve shells was done seasonally throughout four seasons at four stations located on the southwest coast of the Caspian Sea (Astara, Anzali, Kiashahr, and Chabaksar) (Fig. 1). The spatial coordinates of each station were precisely determined by GPS in the first sampling and sampling was done from each station with three repetitions.

The collected samples were stored in a plastic bag and taken to the laboratory. After species identification based on the Invertebrate Atlas of the Caspian Sea (Birshtein et al., 1971) the shells were dried, coded, and measured. A digital scale with an accuracy of four decimal places was utilized to weigh the samples and a digital caliper with an accuracy of two decimal places was used to measure their length. Samples with similar age classes were grouped together after washing and were kept in closed Falcon tubes which were washed previously with double distilled water.

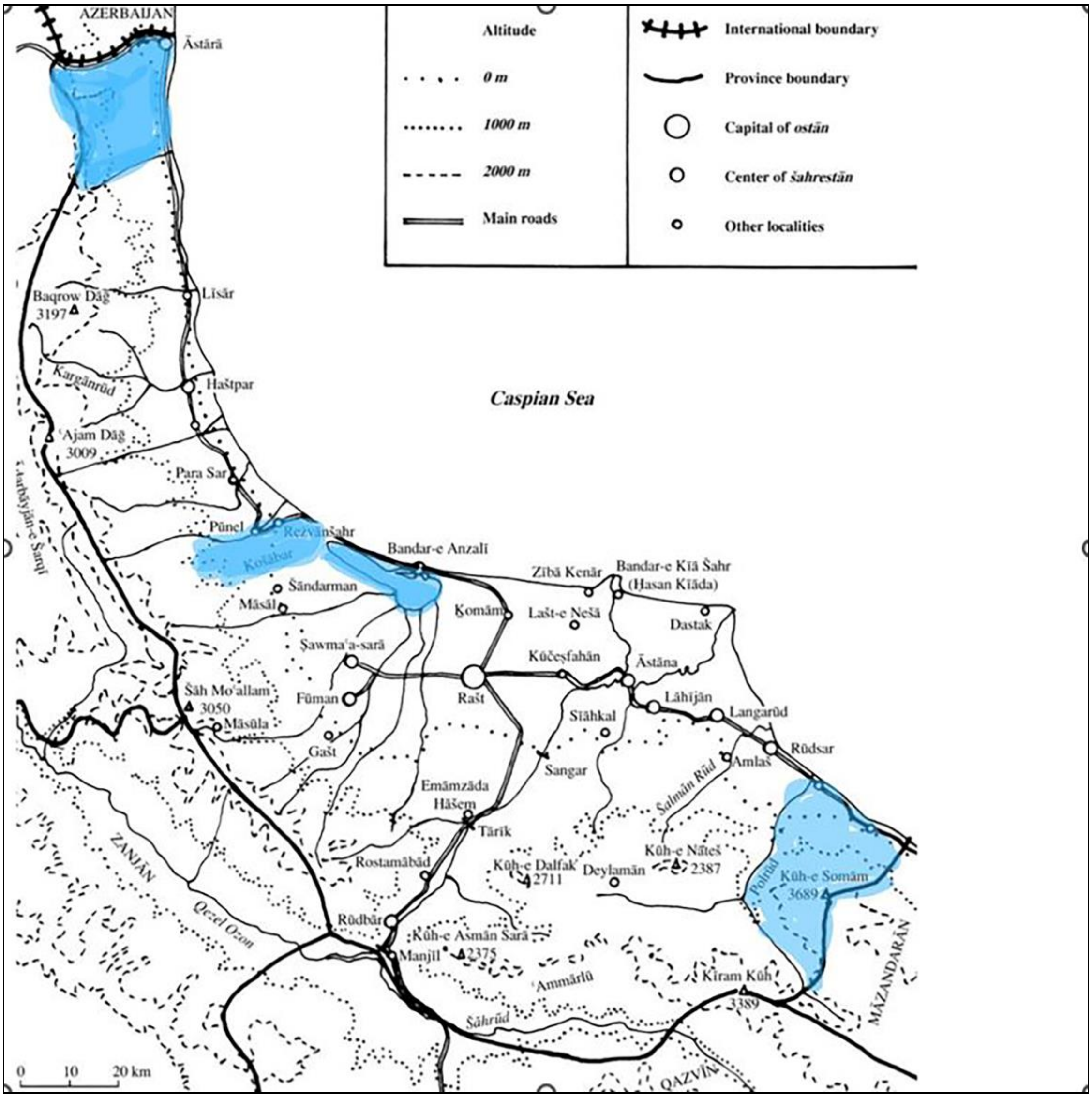


Figure 1: Sampling areas highlighted as blue colour.

The samples obtained from the fin were digested with a mixture of nitric acid (65% $HNO_3$) and perchloric acid (60% $HClO_4$) (2:1 v/v) in a water bath at 70°C in order to degrade organic matter. Distilled water was added to the solution to make a volume of 50 mL. The following trace elements were determined in these samples: Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, In, Ir, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Os, P, Pb, Pd, Pr, Pt, Re, Rh, Ru, S, Sb, Sc, Se, Sm, Sn, Rb, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, and Zr. They were quantified using an inductively coupled spectrometer (ICP-MS), supplied by Agilent as one of their 7500 series machine. The operational conditions for the ICP-MS were optimized in accordance with the manufacturer's instructions. The recovery of the analytical methods was verified utilizing the certified reference materials DORM-5 (National Research Council Canada), REE-1 (Natural Resources

Canada), and single-element standards (Merck) in the case of elements not included in the previous two. According to Yang et al., (2016), the limits of detection (LOD) and quantification (LOQ) of each element were calculated through the analyte concentration that corresponded to three and ten times the standard deviation of ten independent blank measurements respectively. The recovery values for the analytes examined ranged between 96% and 103%. The linearity test showed $R^2$ values above 0.995 for the elements analysed. In the case of rare earth elements, extremely low concentrations were determined. The blanks were similarly processed, and the concentrations were determined with standard solutions prepared in the same matrix.

A boxplot was used to detect outlier data. The data were checked for normality and homogeneity of variance, and data transformation was done if necessary. A correlation test was also used to calculate the correlation and relationship between data. A cluster analysis was performed using the Euclidean distance as the clustering method to determine the possible grouping of trace elements. All statistical analyses were done with SPSS software (Version 26. SPSS Inc., Chicago, IL) and a significance level of 5% was considered. Excel (Version 2016) was used to draw the graph.

Since all animal handling was done under the Iranian and European guidelines on animal welfare, and the waste matter was used for distinctive purposes, no ethical committee approval was necessary.

## RESULTS AND DISCUSSION

Utilizing aragonitic bivalve shells of *Ceratoderma* can validate a powerful proxy response to environmental variations. For the objectives of this investigation, we used a constant seasonal growth model. However, variations in growth rates among individuals in different sites and/or seasons may generate an offset in element chemical records. This should be considered while interpreting data (Tab. 1).

Table 1: The length, weight and age range of *Ceratoderma* in the station in different seasons.

| Station | Season | Length range (mm) | Weight range (gr) | Age range (year) |
|---|---|---|---|---|
| Astara | Spring | 8.7-24 | 0.6-2.0 | 1-4 |
| | Summer | 7.5-28.5 | 0.05-2.6 | 1-4 |
| | Autumn | 0.8-2 | 0.03-2 | 1-4 |
| | Winter | 0.67-2.6 | 0.06-2.6 | 1-4 |
| Anzali | Spring | 0.59-2.3 | 2.7-0.02 | 1-3 |
| | Summer | 7-24 | 0.05-3.3 | 1-3 |
| | Autumn | 0.59-2.3 | 0.02-2.7 | 1-3 |
| | Winter | 1.2-2.5 | 0.2-2.1 | 1-3 |
| Kiashahr | Spring | 16-25 | 0.2-2.1 | 1-3 |
| | Summer | 12-25 | 0.2-2 | 1-3 |
| | Autumn | 1-2.2 | 0.1-1.1 | 1-3 |
| | Winter | 0.83-2.2 | 0.04-1.7 | 1-3 |
| Chaboksar | Spring | 9-28 | 0.11-2.1 | 1-4 |
| | Summer | 7.9-25.6 | 0.05-3 | 1-4 |
| | Autumn | 1-2.3 | 0.2-2.2 | 1-4 |
| | Winter | 0.47-2.5 | 0.02-1.4 | 1-4 |

Concentrations of the elements found in the shells of *Ceratoderma* are listed highest to lowest based on the mean concentration and the upper and lower quartiles, expressed in µg/kg except Ca with expressed mg/kgin (Tab. 2).

Table 2: The concentrations of the elements determined in the shells of *Ceratoderma*, based on the mean concentration minimum, maximum, and standard deviation.

| Element | N | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|---|
| Al (ppb) | 44 | 15.00 | 8855357.14 | 3263809.21 | 3462769.30 |
| Na (ppb) | 44 | 321028.04 | 4559202.30 | 1916205.16 | 1427612.22 |
| Sr (ppb) | 44 | 3071.20 | 2895438.87 | 892340.37 | 951565.85 |
| K (ppb) | 44 | 32646.05 | 1651788.99 | 581615.02 | 591305.65 |
| Mg (ppb) | 44 | 112410.07 | 988478.45 | 423808.17 | 282886.81 |
| S (ppb) | 44 | 78.53 | 909375.00 | 318254.63 | 327867.42 |
| Ca (ppm) | 44 | 228404.85 | 492417.76 | 298984.77 | 73251.40 |
| P (ppb) | 44 | 3916.41 | 665397.32 | 244276.31 | 245956.09 |
| Ti (ppb) | 44 | 0.95 | 707943.93 | 164167.09 | 192783.64 |
| Fe (ppb) | 44 | 23200.00 | 330172.41 | 120591.02 | 69436.37 |
| B (ppb) | 44 | 14048.53 | 513934.43 | 94119.96 | 104085.31 |
| Zn (ppb) | 44 | 1277.14 | 266174.31 | 92122.97 | 95377.01 |
| Sb (ppb) | 44 | 8.78 | 215691.96 | 68104.58 | 74855.32 |
| Ba (ppb) | 44 | 7812.50 | 97692.31 | 52521.20 | 28095.39 |
| Mn (ppb) | 44 | 5468.75 | 227643.93 | 39318.36 | 44655.63 |
| Cr (ppb) | 44 | 4.77 | 363934.43 | 27406.14 | 60945.03 |
| Co (ppb) | 44 | 1.28 | 351639.34 | 20443.81 | 58624.47 |
| Zr (ppb) | 44 | 1.17 | 22015.18 | 7603.93 | 8235.17 |
| As (ppb) | 44 | 6.12 | 25982.14 | 7533.08 | 8460.30 |
| Cu (ppb) | 44 | 4.96 | 132592.62 | 6812.09 | 20645.84 |
| V (ppb) | 44 | 716.96 | 17142.86 | 6397.66 | 5977.95 |
| Li (ppb) | 44 | 854.70 | 14520.14 | 3178.43 | 2530.24 |
| Pb (ppb) | 44 | 96.56 | 56250.00 | 3041.75 | 8329.75 |
| Rb (ppb) | 44 | 4.82 | 94723.53 | 2239.43 | 14267.52 |
| Ni (ppb) | 44 | 5.92 | 6697.25 | 1989.73 | 2310.24 |
| Mo (ppb) | 44 | 28.96 | 2413.76 | 825.06 | 861.77 |
| Hg (ppb) | 44 | 0.66 | 3750.00 | 769.42 | 985.36 |
| Ga (ppb) | 44 | 78.53 | 3985.62 | 718.90 | 1003.06 |
| Y (ppb) | 44 | 7.35 | 2107.76 | 620.73 | 661.93 |
| Ag (ppb) | 44 | 30.41 | 2208.95 | 420.85 | 421.29 |
| Cs (ppb) | 44 | 4.26 | 3128.46 | 130.45 | 464.93 |
| La (ppb) | 44 | 44.72 | 1361.79 | 113.54 | 194.45 |
| U (ppb) | 44 | 14.23 | 205.07 | 96.62 | 41.30 |
| Nd (ppb) | 44 | 6.15 | 1116.54 | 87.43 | 165.04 |

Table 2 (contunued): The concentrations of the elements determined in the shells of *Ceratoderma*, based on the mean concentration minimum, maximum, and standard deviation.

| Element | N | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|---|
| Sc (ppb) | 44 | 10.54 | 1052.21 | 87.20 | 155.35 |
| Se (ppb) | 44 | 12.64 | 377.95 | 85.96 | 71.23 |
| Pd (ppb) | 44 | 9.95 | 143.68 | 83.29 | 39.00 |
| Lu (ppb) | 44 | 20.00 | 140.19 | 77.76 | 32.28 |
| Te (ppb) | 44 | 3.26 | 140.19 | 75.09 | 37.90 |
| Be (ppb) | 44 | 6.00 | 140.19 | 74.51 | 39.22 |
| Th (ppb) | 44 | 1.30 | 272.64 | 70.19 | 55.00 |
| Ta (ppb) | 44 | 1.16 | 140.19 | 70.19 | 42.83 |
| Ce (ppb) | 44 | 7.15 | 140.19 | 67.26 | 43.34 |
| Sn (ppb) | 44 | 6.76 | 300.24 | 67.19 | 58.96 |
| Cd (ppb) | 44 | 10.00 | 140.19 | 62.09 | 45.71 |
| W (ppb) | 44 | 6.00 | 140.19 | 60.61 | 46.58 |
| Pr (ppb) | 44 | 1.14 | 299.00 | 60.46 | 64.02 |
| Sm (ppb) | 44 | 0.91 | 215.24 | 60.11 | 56.41 |
| Tb (ppb) | 44 | 0.63 | 140.19 | 59.35 | 49.06 |
| Yb (ppb) | 44 | 0.71 | 140.19 | 59.04 | 51.04 |
| Tl (ppb) | 44 | 0.95 | 140.19 | 58.50 | 48.97 |
| Gd (ppb) | 44 | 0.50 | 226.60 | 57.65 | 59.49 |
| Bi (ppb) | 44 | 4.00 | 140.19 | 57.48 | 49.96 |
| Dy (ppb) | 44 | 1.37 | 157.52 | 56.30 | 55.50 |
| Tm (ppb) | 44 | 7.03 | 140.19 | 56.00 | 50.79 |
| Os (ppb) | 44 | 7.20 | 140.19 | 55.99 | 50.88 |
| Ru (ppb) | 44 | 3.17 | 140.19 | 55.47 | 51.45 |
| Nb (ppb) | 44 | 6.00 | 140.19 | 55.15 | 51.64 |
| Er (ppb) | 44 | 0.50 | 140.19 | 53.99 | 54.52 |
| Hf (ppb) | 44 | 0.61 | 140.19 | 53.54 | 53.17 |
| Eu (ppb) | 44 | 0.51 | 140.19 | 53.37 | 54.09 |
| Ir (ppb) | 44 | 1.26 | 140.19 | 53.25 | 53.38 |
| Re (ppb) | 44 | 1.51 | 140.19 | 53.09 | 53.54 |
| Ho (ppb) | 44 | 0.53 | 140.19 | 52.54 | 54.26 |
| In (ppb) | 44 | 0.50 | 140.19 | 52.09 | 54.44 |
| Rh (ppb) | 44 | 0.54 | 140.19 | 52.06 | 54.47 |
| Pt (ppb) | 44 | 0.72 | 140.19 | 51.95 | 54.58 |

The majority of water entering the Caspian Sea flows through the rivers Sefidrood and Anzali Lagon in the southern zone (Ataei et al., 2019). Given their geographical location, they flow through the majority of the south Caspian Sea's urban, agricultural, and industrial sectors, potentially polluting it (Nematollahi et al., 2021). Domestic and industrial activities in developing countries release enormous amounts of harmful pollutants, including trace elements, into waterways (Akhtar et al., 2021). Moreover, trace metals with higher concentrations in these zones, such as Al, Cd, As, and Hg, are frequently found in crude oil (Saleh et al., 2021) which seems to indirectly come with the currents. Furthermore, the discharge of agricultural wastewater is tainted with pesticides or fertilizers, in which trace metals are abundant (Fu et al., 2021). Considering these points, the presence of elements such as As, Cd, and Hg could be attributed to the river's closeness to more developed sectors.

The figure 2 grouped all elements except Al in one major group which was followed by two sub-groups; first sub-group included Na and Sr and the second included all major group elements except Na and Sr. On the clustering analysis, two groups were established. Except for Al which stands separately, the similarity between the groups may be due to natural factors, a common origin, and physicochemical properties of the elements (Bakhshalizadeh et al., 2023).

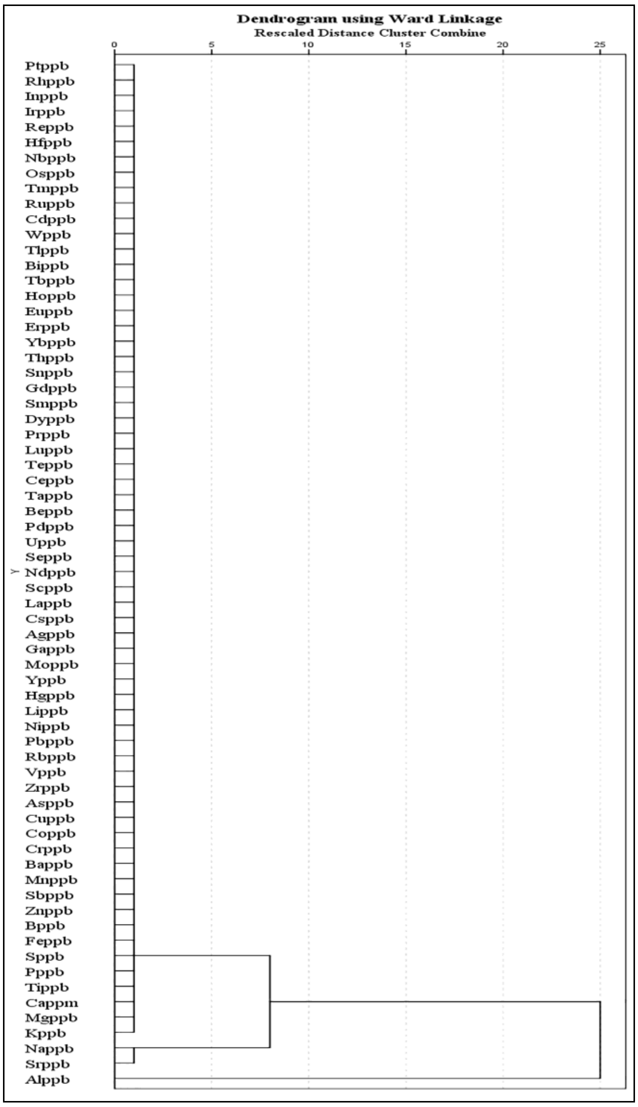

Figure 2: Trace element grouping in shells of *Ceratoderma* based on the Ward linkage.

Finding the correlation among elements in bio-indicator aquatic organisms save time and costs when used as environmental proxies (Lomartire et al., 2021). Here, the correlation was not seen in elements of aragonitic bivalve shells such as B, Ba, Pd, U, Ag, Fe, Co, Cs, Ga, La, Se, although strong positive correlations ($r \geq 0.9$ $n = 44$ $p < 0.05$) were seen among: Ca with Lu and Cd; Gd with Th; Ho with Be, Lu, Ca, Cd and Gd; Li with Ca; Pr with Gd and Th; Sm with Th, Gd, Ho and Pr; Sn with Th, Gd, Sm and Pr; Tb with Lu, Ca, Cd, Ho and Sm; Te with Cd, Ho and Tb; Tl with Be, Lu, Ca, Cd, Gd, Ho, Sm, Tb and Te; Bi with Be, Lu, Ca, Cd, Gd, Ho, Sm, Tb, Tl and Te; Ce with Lu, Ca, Cd, Ho, Tb, Tl and Bi; Cr with Co; Cu with Co and Cr; Dy with Be, Th, Cd, Gd, Ho, Pr, Sm, Sn, Tb, Tl, Bi; Er with Be, Lu, Ca, Cd, Gd, Ho, Pr, Sm, Tb, Tl, Bi, Ce and Dy; Eu with Be, Lu, Ca, Cd, Gd, Ho, Sm, Tb, Tl, Bi, Ce, Er and Dy; Hf with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu and Dy; Hg with Ca, Cd, Ho, Tl, Bi, Eu and Hf; In with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, Hg and Dy; Ir with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, Hg and Dy; K with Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, Hg, Ir, In and Dy; Mg with Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, In, Ir, K and Dy; Mn with Li; Mo with Lu, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, In, Ir, K, Mg and Dy; Na with Cd, Ho, Tb, Tl, Bi, Er, Eu, In, Ir, K, Mg and Mo; Nb with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo and Dy; Nd with Cs and La; Ni with Lu, Cd, Ho, Tb, Tl, Bi, Eu, In, Ir, K, Mo and Nb; Os with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni and Dy; P with Lu, Cd, Ho, Tb, Tl, Bi, Ce, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Os and Dy; Pb with Cs, La and Nd; Pt with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Ni, P, Os and Dy; Re with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Os and Dy; Rh with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Os, Re and Dy; Ru with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Os, Re, Rh and Dy; S with Na; Sb with Lu, Ca, Cd, Ho, Tb, Tl, Bi, Ce, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Os, Re, Rh, Ru and Dy; Sc with Cs, La, Nd and Pb; Rb with Cs, La, Nd, Pb and Sc; Sr with S and Na; Ta with Cd, Ho, Tb, Bi, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Os, Pt, Re, Rh, Ru, Sb and Sr; Ti with Lu, Ca, Cd, Ho, Li, Tb, Tl, Bi, Ce, Dy, Er, Eu, Hf, In, Ir, K, Mg, Mn, Mo, Nb, Ni, P,Pb, Pt, Os, Re, Rh, Ru and Sb; Tm with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Dy, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Os, Re, Rh, Ru and Sb; V with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Dy, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Os, Re, Rh, Ru and Sb; W with Be, Lu, Ca, Cd, Ho, Tb, Te, Tl, Bi, Ce, Dy, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Os, Re, Rh, Ru and Sb; Y with Be, Lu, Ca, Cd, Gd, Ho, Sm, Tb, Te, Tl, Bi, Ce, Dy, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Ta, Ti, Tm, V, W, Os, Re, Rh, Ru and Sb; Yb with Ca, Cd, Gd, Pr, Sm, Tb, Tl, Bi, Ce, Dy, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Ta, Ti, Tm, V, Y, W, Os, Re, Rh, Ru and Sb; Zn with Be, Lu, Ca, Cd, Gd, Ho, Pr, Sm, Tb, Tl, Bi, Ce, Dy, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Ta, Ti, Tm, V, Y, Yb, W, Os, Re, Rh, Ru and Sb; Zr with Be, Lu, Ca, Cd, Ho, Sm, Tb, Te, Tl, Bi, Ce, Dy, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Ta, Ti, Tm, V, Y, Yb, W, Zn, Os, Re, Rh, Ru and Sb; Al with Be, Lu, Ca, Cd, Gd, Ho, Sm, Tb, Te, Tl, Bi, Ce, Dy, Er, Eu, Hf, Hg, In, Ir, K, Mg, Mo, Nb, Ni, P, Pt, Ta, Ti, Tm, V, Y, Yb, W, Zn, Zr, Os, Re, Rh, Ru and Sb; As with Lu, Ca, Cd, Ho, Sm, Tb, Tl, Bi, Ce, Er, Eu, Hf, Hg, In, Ir, K, Mg, Nb, Ni, P, Pt, Ta, Ti, Tm, V, Y, Yb, W, Zn, Zr, Os, Re, Rh, Ru and Sb; B with Co, Cr and Ni. Strong negative correlations ($r \leq -0.9$ $n= 44$ $p < 0.05$) were found among: Na with Cd, Ho, Tb, Tl, Bi, Er, Eu, Hf, In, Ir, K, Mg and Mo; P with Na; Pt, Rh, Ru, Re with Na; S with Cd, Ho, Tb, Tl, Bi, Er, Eu, Hf, In, Ir, K, Mg, Mo, Nb, Os, P, Pt, Re, Rh and Ru; Sb with Na and S; Sr with Cd, Tb, Tl, Hf, In, Ir, K, Mo, Nb, Os, Pt, Re, Rh, Ru and Sb; Ti with S and Na; Tm with S and Na; V with S and Na; W with S and Na; Yb with S and Na; Zn with S and Na; Zr with Sr, S, and Na; Al with Sr, S, and Na; As with S and Na.

Further research in this field could focus on exploring the relationships between different elements in bivalve shells and how these interactions may influence shell structure and function. Investigating the mechanisms by which bivalves incorporate and regulate elemental uptake in their shells could also provide valuable insights into potential adaptation strategies in response to changing environmental conditions.

## CONCLUSIONS

In conclusion, the literature on elementcorrelation in the shell of bivalves contributes to our understanding of the complex interactions between organisms and their environment. This research not only has significant implications for environmental monitoring and biomonitoring efforts but also opens up new avenues for exploring the physiological and ecological significance of elemental composition in bivalve shells. Further research in this field is warranted to uncover the underlying mechanisms and potential applications for conservation and management efforts.

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