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RESEARCH ARTICLE

Metal variability in small pelagic fish *Scomber colias* as influenced by volcanic events in the Canary Islands

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Abstract
Offshore volcanic activity occurs when an underwater volcano erupts. These volcanoes can be located underwater or on land and can be very dangerous to marine life. The aim of this study is to examine whether the influence of two volcanoes has an effect on the concentrations of metals and trace elements in the Atlantic mackerel *Scomber colias* in the Canary Islands. For the study, ten specimens of *S. colias* were obtained from each sampling area in March 2022. Metal concentrations were determined by inductively coupled plasma optical emission spectrophotometry (ICP-OES). The specimens of *Scomber colias* from the area affected by the Tajogaite volcano (La Palma) showed higher concentrations of all metals and trace elements analyzed than those from the other study areas. The specimens from the area of influence of the Tagoro Volcano (El Hierro) showed the second highest concentration of the elements studied, although this volcanic process is in a state of degassing.

Keywords Volcanic · Metal · Trace element · Canary Islands

Introduction

Submarine volcanoes are volcanoes that lie at the bottom of the ocean and were formed by underwater volcanic activity, being responsible for most of the volcanic activity on Earth (Arnulf et al. 2014; Hübscher et al. 2015; Nomikou et al. 2013). Submarine volcanoes are also the origin of many mineral deposits (Ariza et al. 2014; Butterfield et al. 2011; Fraile-Nuez et al. 2012). During a submarine volcanic eruption, metal-rich magma rises from the Earth's mantle to the ocean floor. Upon contact with seawater, the magma rapidly cools and solidifies, releasing volcanic gases and dissolved metals. Common metals emitted include iron, copper, zinc, lead, and aluminum. Submarine volcanoes are also sites of intense hydrothermal activity. Sea water penetrates fractures in the oceanic crust, is heated by contact with hot magmatic rocks, and then rises back to the seafloor. During this process, the hot water dissolves metals from the surrounding rocks. When the metal-laden hydrothermal fluid emerges at the bottom of the ocean, it cools rapidly and precipitates the metals, forming metal sulfide deposits (Álvarez-Valero et al. 2018; Gibson et al. 1997; Lozano-Bilbao et al. 2018; Santana-Casiano et al. 2016; Santana-González et al. 2017; Torres et al. 2023).

Fish contamination is a serious environmental problem that affects the health of aquatic ecosystems (Azaman et al. 2015; Khalili Tilami and Sampels 2018). Contamination may arise from various origins, including industrial chemicals, volcanic activity, human and animal waste, and mining byproducts. These pollutants can lead to a range of

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adverse consequences, including growth inhibition, poisoning, reduced fertility, altered behavior patterns, disease, and potentially mortality (Bencheikh et al. 2022; Bonsignore et al. 2018; du Preez and Wepener 2016; Watson et al. 2013). Pollution can also have a negative effect on fish populations by reducing the number of healthy spawners. Furthermore, fish can transport toxic materials and pass them on to other aquatic organisms through the food chain, leading to a variety of adverse effects (Brock and Bielmyer 2013; Bryan and Darracott 1979; Kishigami and Savelle 2005; Schlehe and Yulianto 2020). Bioaccumulation is the process by which a fish accumulates metals in its tissues, and it depends on various factors including the fish species, age, size, metabolic rate, and environmental conditions. Some fish species may have a greater capacity to accumulate metals than others, and certain environmental conditions such as water temperature and pH can influence the availability and absorption of metals by fish. Once metals are accumulated in the fish's tissues, they can persist for extended periods due to the slow rate of metal elimination from the organism. This means that metals can accumulate in increasingly higher concentrations as the fish continues to be exposed to sources of contamination in its environment (Bryan and Darracott 1979; Franke et al. 1994; Morel et al. 1998; Murphy and Spiegel 1982; Rakib et al. 2022; Ray 1984).

Since 2011, two notable volcanic eruptions have been recorded in the Canary Islands. In that year, the island of El Hierro witnessed the emergence of the submarine volcano Tagoro. Located to the south of the island, its eruptive activity began in 2011 and is currently in a degassing phase, releasing various gases rich in metals and trace elements (González-Vega et al. 2020; Santana-González et al. 2017). On the other hand, in 2021, La Palma witnessed the onset of eruptive activity of the terrestrial volcano Tajogaite, located in the central area of the island. The lava generated by this eruption reached the coast, creating a volcanic delta in the central-western region, where gases and elements continue to be emitted into the ocean (Carracedo et al. 2022; Román et al. 2022).

The aim of this study is to examine whether the influence of two volcanoes has an effect on the concentrations of metals and trace elements in the Atlantic chub mackerel *Scomber colias* Gmelin, 1789, a coastal pelagic fish species abundant in the Canary Islands.

Material and methods

Sampling areas

Two study areas were chosen, one off the island of El Hierro and the other off the island of La Palma, each affected by a different volcano, the Tagoro Volcano in the former and the Tajogaite Volcano in the latter. The Tajogaite Volcano, terrestrial, is in the central area of La Palma (Fig. 1). To compare the following, two other areas were chosen as zones currently unaffected by volcanic activity: the southern area of the island of Gran Canaria (Arguineguín) and the southeastern area of the island of Lanzarote (Puerto del Carmen) (Fig. 1). Ten specimens of *S. colias* were obtained for the study in each sampling area in March 2022, and the total length (in cm) of each individual was measured. This species has been chosen because it is common throughout the Canary archipelago and of great fishing interest. *S. colias*, commonly known as horse mackerel, belongs to the Animalia kingdom, Chordata phylum, Actinopterygii class, Perciformes order, and Scombridae family. This fish species has an elongated, fusiform body, with silver coloration on the flanks and a series of vertical dark bands on the sides.

Sample preparation

Five grams of muscle tissue from the *S. colias* specimens was used for the analyses; only muscle samples were taken because many fishermen gave us eviscerated specimens. The samples were dried for 24 h in an oven, at a temperature of 70°C. After drying the samples, they were placed in a muffle furnace at 450 ± 25°C until white ashes were obtained. These ashes were filtered and made up to a total volume of 10 ml with a 1.5% HNO_3 solution. After sample preparation, metal concentrations were determined by inductively coupled plasma optical emission spectrophotometry (ICP-OES), using the ICAP 6300 model (Duo Thermo Scientific, Waltham, MA, USA) with an attached auto sampler (Auto Sampler, CETAX model ASX-520); results for metals are given in mg/kg wet weight.

In addition, a quality control solution was used to evaluate the accuracy of the determinations in every sample. The accuracy of the analytical procedure was evaluated by analyzing the international standard reference materials DORM-1 and DORM-5 (National Research Council of Canada). The recovery obtained with the reference materials was higher than 97%. Blanks and standard reference materials were analyzed along with the samples. The validation parameters that were verified in this analytical method were specificity, precision (established as reproducibility), and accuracy (stated as recovery). These parameters were verified with the measurement, under reproducibility conditions, of abovementioned reference materials (ten times each). The results of the verification procedure were the following: specificity, the method was found to be free of spectral interference for each of the metals studied; the recovery achieved with the reference materials fell within the range of 97 to 103.1%. Instrumental detection and quantification limits were established by assessing the instrumental response of the equipment, specifically by analyzing 15 targets under

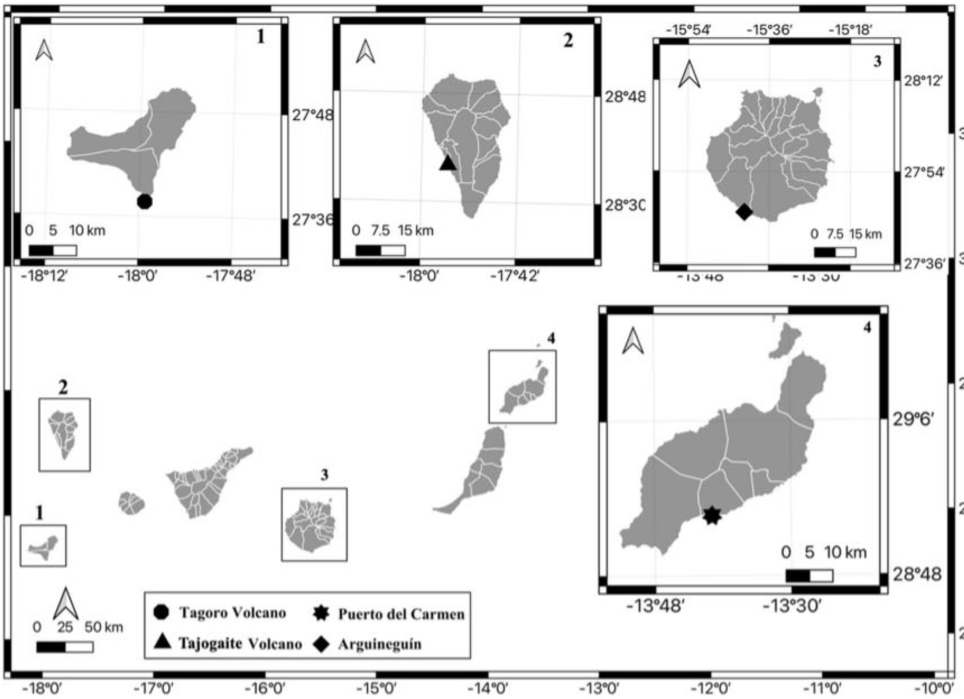

Fig. 1 Map of the Canary Islands showing the four selected areas

reproducibility conditions (Table 1). Blanks and standard reference materials were assessed concurrently with the samples. All data is presented in milligrams per kilogram, dry weight, and the metals analyzed included Al, Cd, Cu, Fe, Li, Pb, and Zn (Lozano-Bilbao et al. 2023).

Statistical analysis

A permutational multivariate analysis of variance (PERMANOVA) with Euclidean distances was performed to determine the existence of differences in the content and

Table 1 Descriptive statistics of the variables analyzed (mean ± standard deviation (minimum–maximum)). The total length is given in cm and the metal concentrations in mg/kg w.w

	Tagoro Volcano	Arguineguín	Tajogaite Volcano	Puerto del Carmen
Total length	36.0 ± 1.2 (33.1–37.2)	36.8 ± 1.1 (35.4–39.5)	36.3 ± 0.9 (33.9–37.1)	36.2 ± 1.2 (33.9–38.4)
Al	6.974 ± 0.586 (6.096–7.887)	5.608 ± 0.520 (5.014–6.769)	10.767 ± 0.604 (9.748–11.540)	6.088 ± 0.825 (5.060–7.842)
Zn	7.926 ± 0.727 (6.644–8.975)	7.516 ± 1.093 (6.266–9.920)	11.710 ± 1.580 (9.023–14.284)	6.854 ± 0.554 (6.131–7.706)
Cd	0.153 ± 0.009 (0.137–0.165)	0.135 ± 0.015 (0.119–0.172)	0.196 ± 0.020 (0.174–0.242)	0.13 ± 0.015 (0.114–0.168)
Pb	0.016 ± 0.001 (0.015–0.018)	0.012 ± 0.002 (0.009–0.014)	0.018 ± 0.002 (0.015–0.022)	0.012 ± 0.002 (0.009–0.015)
Fe	15.937 ± 0.821 (14.376–16.888)	13.350 ± 1.504 (11.158–15.458)	21.114 ± 2.436 (18.067–25.184)	15.566 ± 1.873 (13.767–19.299)
Cr	0.097 ± 0.004 (0.092–0.102)	0.054 ± 0.008 (0.047–0.069)	0.144 ± 0.027 (0.112–0.174)	0.081 ± 0.003 (0.077–0.085)
Cu	1.703 ± 0.166 (1.420–1.837)	1.521 ± 0.246 (1.205–1.894)	2.180 ± 0.258 (1.844–2.646)	1.382 ± 0.142 (1.179–1.525)
Li	12.428 ± 0.375 (12.057–13.052)	10.560 ± 0.683 (10.025–12.193)	15.226 ± 0.925 (14.540–17.558)	10.591 ± 0.683 (10.009–11.931)

relative composition of heavy metals and trace metals between the samples analyzed. A one-way design was used with the fixed factor of "zone," with four levels of variation (Tagoro Volcano, Tajogaite Volcano, Arguineguín, and Puerto del Carmen). The variables, aluminum (Al), zinc (Zn), cadmium (Cd), lead (Pb), iron (Fe), chromium (Cr), copper (Cu), and lithium (Li), and 9999 interchangeable unit permutations and pairwise post hoc comparisons were used to verify the differences between the levels of the significant factors (value $p < 0.05$) The calculations were performed with the statistical packages PRIMER 7 and PERMANOVA þ v.1.0.1 (Anderson and Braak 2003; Anderson 2004).

Results and discussion

Table 1 shows the descriptive statistics of *S. colias* from the four study areas. Table 2 shows that the mean total lengths of the specimens were similar to each other in the 4 zones, with no significant differences between them. In the present study, therefore, the size of the specimens would not have an influence as a dependent variable, since the size is similar in the four areas. According to European Union regulations, only Pb and Cd are regulated among the metals studied in our research. They provide maximum values for this species of 0.3 mg/kg for Pb and 0.1 mg/kg for Cd. Our specimens contained lower concentrations of Pb than those regulated. However, for Cd, concentrations exceeded the regulated levels in all study areas, indicating the need for more rigorous monitoring to control Cd concentrations in this species (Regulation (UE) 2023/915 2023).

The PERMANOVA statistical analysis was employed to compare the different study areas for each variable (Tl, Al, Zn, Cd, Pb, Fe, Cr, Cu, and Li) using a significance threshold of $p = 0.05$. For the variable Tl, no significant differences were found among the groups. However, for the variable Al, significant differences were observed between Arguineguín and Tagoro Volcano, as well as between Arguineguín and Tajogaite Volcano. Regarding Zn, significant differences were found between Puerto del Carmen and Tagoro Volcano, as well as between Puerto del Carmen and Tajogaite Volcano. For Cd, all comparisons showed significant differences between the groups. The same occurred with the variables Pb, Cr, Cu, and Li, where all comparisons yielded significant differences between the groups. Particularly noteworthy are the results for Fe, where significant differences were observed between Arguineguín and Tagoro Volcano, as well as between Arguineguín and Tajogaite Volcano, Puerto del Carmen and Tagoro Volcano, and between Tagoro Volcano and Tajogaite Volcano. In summary, these tests reveal significant differences in multiple variables among the study areas, suggesting variability in contamination levels among them (Table 2).

As for aluminum (Al), the specimens from Arguineguín (Gran Canaria) and Puerto del Carmen (Lanzarote) did not show significant differences between the two areas, with the specimens from Arguineguín showing the lowest concentration (5.608 ± 0.520 mg/kg) compared to the other zones. The areas affected by the Tagoro Volcano (El Hierro) and the Tajogaite Volcano (La Palma) show significant differences with respect to all the zones analyzed, even between samples from both areas, with samples from the vicinity of the La Palma showing the highest aluminum concentration of 10.767 ± 0.604 mg/kg (Tables 1 and 2). The concentrations ordered from highest to lowest were as follows: Tajogaite Volcano > Tagoro Volcano > Puerto del Carmen > Arguineguín (Fig. 2). Aluminum is a chemical element present in the Earth's crust and, therefore, in volcanoes. They are a source of aluminum, as they contain volcanic minerals including this metal, such as andesite and diorite. These

Table 2 Results of pairwise tests examining the significant factor "Zone" obtained in a one-way ANOVA analyzing the metal content variation and total length

	Groups					
	Arguineguín vs. Puerto del Carmen	Arguineguín vs. Tagoro Volcano	Arguineguín vs. Tajogaite Volcano	Puerto del Carmen vs. Tagoro Volcano	Puerto del Carmen vs. Tajogaite Volcano	Tagoro Volcano vs. Tajogaite Volcano
Total length	0.411	0.232	0.438	0.694	0.872	0.549
Al	0.215	0.002*	0.001*	0.046*	0.001*	0.001*
Zn	0.192	0.414	0.001*	0.01*	0.001*	0.001*
Cd	0.588	0.025*	0.001*	0.009*	0.001*	0.001*
Pb	0.713	0.001*	0.001*	0.001*	0.001*	0.047*
Fe	0.044*	0.002*	0.001*	0.577	0.002*	0.001*
Cr	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
Cu	0.226	0.032*	0.001*	0.007*	0.001*	0.002*
Li	0.923	0.003*	0.001*	0.001*	0.001*	0.001*

*$p > 0.05$

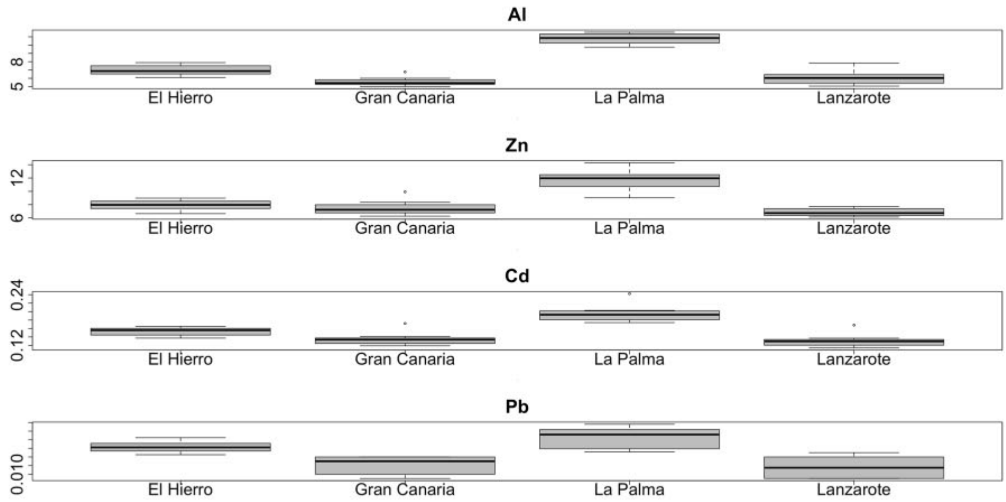

Fig. 2 Boxplot of the study areas for Al, Zn, Cd, and Pb (mg/kg). El Hierro, Tagoro Volcano; Gran Canaria, Arguineguín; La Palma, Tajogaite Volcano; Lanzarote, Pto. del Carmen

minerals are formed during the eruption when the magma cools and solidifies. Aluminum can also be found in liquids emitted from volcanoes, such as ice, which contains extremely small amounts of the metal. Furthermore, aluminum can be released into the air during a volcano eruption, and then deposited on nearby soils (Imura et al. 2019; Matus et al. 2006). This may explain why specimens near the two volcanoes have a higher concentration of aluminum. In the study carry out by Lozano-Bilbao et al. (2022), it was observed that cephalopod samples from the Tagoro Volcano area had a higher aluminum concentration than those obtained from other areas not influenced by volcanoes.

In the case of zinc (Zn), no significant differences were observed between specimens from Arguineguín and those from Puerto del Carmen, nor between those from Arguineguín and those from the area affected by the Tagoro Volcano, with individuals from Puerto del Carmen having the lowest Zn concentrations (6.854 ± 0.554 mg/kg). Samples from the area affected by the Tajogaite Volcano showed significant differences with respect to those obtained in the other three study areas (11.710 ± 1.580 mg/kg) (Tables 1 and 2). The concentrations in descending order were as follows: Tajogaite Volcano > Tagoro Volcano > Arguineguín > Puerto del Carmen (Fig. 2). Zinc is a chemical element often found in volcanoes, due to the exposure of volcanic rock to water, air, and other liquids, which release zinc into the environment. This element can be found in volcanic ash that fertilizes the ocean. Zinc can bind to fine particles in the air, leading to deposition of the element in soils near volcanoes. Therefore, volcanoes can be an important supply of zinc to nearby ecosystems (Alfieris et al. 2013; Gargano et al. 2022; Pekov et al. 2015; Roshan et al. 2018). Lozano-Bilbao et al. (2022) observed that cephalopod samples from the Tagoro Volcano area had higher zinc concentrations than those from other areas not affected by volcanic activity.

As for cadmium (Cd), no significant differences were observed between specimens from Arguineguín and Puerto del Carmen. *S. colias* from the area affected by the Tajogaite Volcano presented the highest cadmium concentrations of 0.196 ± 0.020 mg/kg, and those from Puerto del Carmen the lowest concentrations of 0.131 ± 0.015 mg/kg (Tables 1 and 2). The concentrations in descending order were as follows: Tajogaite Volcano > Tagoro Volcano > Arguineguín > Puerto del Carmen (Fig. 2). This can be explained by the fact that cadmium is present in minerals such as siderite, chalcopyrite, and sphalerite, which are found in volcanic rocks. The degree of cadmium concentration in volcanoes varies according to geographic location. This metal is released into the environment when volcanoes erupt, which means that the air, water, and soil near the volcano are affected by elevated levels of cadmium. This element can also enter the food chain and be harmful to human health (Bach et al. 2014; Torres et al. 2023; World Health Organitation 1992). Lozano-Bilbao et al. (2022, 2018) reported that cephalopod specimens from the area affected by the Tagoro Volcano had higher cadmium concentrations than the other areas not affected by volcanoes.

Lead (Pb) showed the same pattern as cadmium. Significant differences in lead concentrations were only observed between the specimens collected in Arguineguín and Puerto del Carmen. Samples obtained in the area affected by the Tajogaite Volcano showed the highest concentrations of

0.018 ± 0.002 mg/kg (Tables 1 and 2). The concentrations from highest to lowest were as follows: Tajogaite Volcano > Tagoro Volcano > Arguineguín > Puerto del Carmen (Fig. 2). This may be due to the fact that lead is found in volcanic eruptions mainly as a result of the presence of minerals such as galena. These minerals are formed during the magma formation process and are present in the magma and released in the form of gases, volcanic ash, and fine particles (Prestvik et al. 2001; Sun 1980; Tatsumoto 1966; Zheng et al. 2022). Lozano-Bilbao et al. (2020) observed that cephalopod individuals obtained in Tagoro Volcano had a higher concentration of lead than those captured in areas not affected by volcanic processes.

With respect to iron (Fe), significant differences were observed among individuals from all study zones, with the exception of the Tagoro Volcano area and Puerto del Carmen. Specimens from the area affected by the Tajogaite Volcano presented the highest iron concentrations, 21.114 ± 2.436 mg/kg (Tables 1 and 2). The concentrations ordered from highest to lowest were as follows: Tajogaite Volcano > Tagoro Volcano > Puerto del Carmen > Arguineguín (Fig. 3). The similarity observed in the iron concentrations of the samples from Puerto del Carmen and the area affected by the Tagoro Volcano may be due to the fact that iron is found in volcanoes in the form of minerals, such as magnetite, hematite, and siderite, and in the form of iron oxide. These minerals and oxides are formed from the oxidation of the metallic elements present in the magma. Iron is one of the most abundant elements in volcanoes and is one of the main components of volcanic ash. Iron can also come from the erosion of volcanic rock, which contains iron-rich minerals (Ayris and Delmelle 2012; Duggen et al. 2010; Omoregie et al. 2008). In addition, the island of Lanzarote is strongly influenced by the upwelling of northwest Africa and by Saharan dust, two phenomena that introduce into the environment compounds rich in elements such as iron. Lozano-Bilbao et al. (2022) found higher iron concentrations in cephalopod samples from the area affected by the Tagoro Volcano than from areas not influenced by volcanic activity.

On the other hand, all study areas showed significant inter-zone differences in chromium (Cr) concentrations in *S. colias* specimens, with individuals from the Tajogaite Volcano showing the highest concentrations with a mean value of 0.144 ± 0.027 mg/kg (Tables 1 and 2). The concentrations from highest to lowest were as follows: Tajogaite Volcano > Tagoro Volcano > Puerto del Carmen > Arguineguín (Fig. 3). This is because chromium is a chemical element that occurs naturally in volcanic eruptions. This element is present in silicate minerals, such as andesite, basalt, and rhyolite, and is also found in lower concentrations in volcanic ash. Chromium is also found in volcanic sediments and soils, due to the process of erosion (Ailow et al. 2019; Hanski and Kamenetsky 2013; Krull-Davatzes et al. 2010). Lozano-Bilbao et al. (2022, 2018) observed higher chromium concentrations in cephalopod specimens from the Tagoro Volcano area than in those from zones not affected by volcanic activity.

In the case of copper (Cu), *S. colias* specimens from Tajogaite Volcano had the highest copper content, with mean concentration of 2.180 ± 0.258 mg/kg (Tables 1 and 2). The concentrations in descending order from highest to lowest were as follows: Tajogaite Volcano > Tagoro

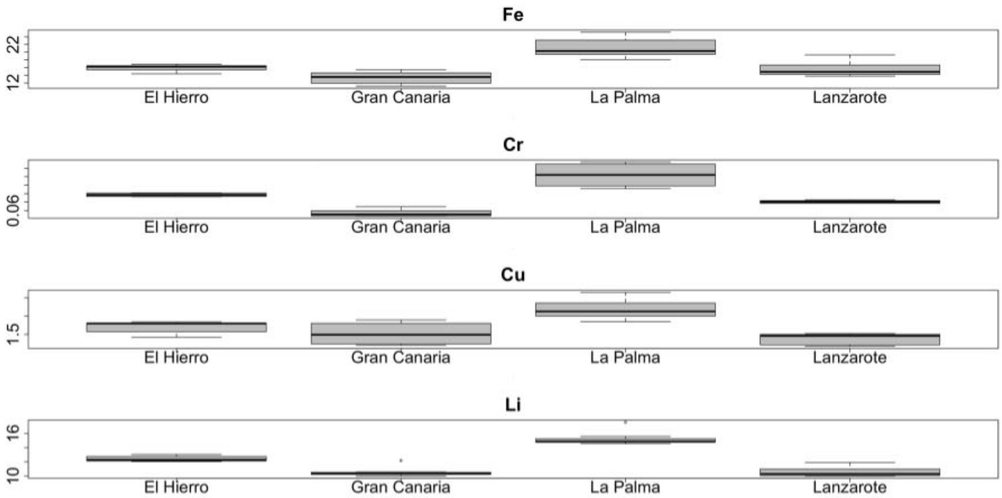

Fig. 3 Boxplot of the study areas for Fe, Cr, Cu, and Li (mg/kg). El Hierro, Tagoro Volcano; Gran Canaria, Arguineguín; La Palma, Tajogaite Volcano; Lanzarote, Pto. del Carmen

Volcano > Arguineguín > Puerto del Carmen (Fig. 3). Copper is often found in volcanoes, as this metal is one of the most common elements in the Earth's crust; it is present in igneous rocks and magma and is released into the atmosphere during periods of volcanic activity. Copper can be found in volcanic ash and can also be present in minerals found inside the volcano, such as copper oxides, copper sulfides, copper carbonates, and copper silicates. Copper can also be found in volcanic rock deposits that form during periods of volcanic activity and, with outgassing, copper compounds are released into the environment (Balassone et al. 2019; Blossom 2007; Yeats and Campbell 1983). Lozano-Bilbao et al. (2018) found higher copper concentrations in cephalopod specimens from the area affected by the Tagoro Volcano than those from other areas not affected by volcanic processes.

With respect to lithium (Li), specimens from the area affected by the Tajogaite Volcano had the highest concentrations, with a mean value of 15.226 ± 0.925 mg/kg (Tables 1 and 2). The concentrations from highest to lowest were as follows: Tajogaite Volcano > Tagoro Volcano > Arguineguín > Puerto del Carmen and (Fig. 3). Lithium occurs naturally in the mineral deposits of volcanoes, usually in clay minerals and other volcanic sediments. These minerals are formed when volcanoes erupt and expel volcanic material, which contains suspended minerals. Lithium is also found in groundwater around volcanoes. The most common form of lithium in volcanoes is lithium borosilicate, which is found in igneous rocks. Igneous rocks contain lithium-rich minerals, such as spodumene and petalite (Cullen et al. 2021; Guo et al. 2018; Nadeau et al. 2021; Zeng et al. 2022).

The results obtained from the specimens of Volcan de Tajogaite and Tagoro show significantly higher values than those found on other islands unaffected by volcanic emissions. Such high values have not been observed in any other study of *S. colias*, not even in anthropogenically contaminated areas. Therefore, it is of vital importance to initiate an environmental monitoring program for this species and other commercially important species to verify whether the species caught in these areas are suitable for human consumption. Environmental monitoring of sea pollution provides crucial scientific data for assessing the extent of the issue, identifying sources of contaminants, implementing measures to reduce pollution, and making informed decisions for the sustainable management of marine resources. It also contributes to raising awareness among society and policymakers about the importance of protecting our oceans and encourages taking actions to prevent and reduce marine pollution (Bouzzammit et al. 2022; Kwaansa-Ansah et al. 2019; Motta et al. 2021; Prego et al. 2020; Raimundo et al. 2013; Steinhausen et al. 2022).

In Bubach et al. (2015), they examined metal concentrations in salmonid species in Patagonia, with volcanic influence, obtaining Zn values of 56 ± 42 mg/kg dw. Although the value is given in wet weight, it remains very high compared to our study. This could be attributed to the high volcanic activity in the area and the ocean's high metal and nutrient content due to marine currents. Torres et al. (2016) studied Cd and Pb concentrations in two tuna species in the Azores, a region very similar to the Canary Islands with volcanic activity. In the species *Thunnus obesus*, they obtained values of 0.186 ± 0.058 mg/kg ww of Cd and 0.036 ± 0.001 mg/kg ww of Pb. For the species *K. pelamis*, they obtained values of 0.155 ± 0.059 mg/kg ww of Cd and 0.152 ± 0.028 mg/kg ww of Pb. The results in *K. pelamis* are very similar to those obtained in our study for specimens from the Tajogaite volcano in La Palma and very similar to those from the Tagoro volcano in El Hierro. This is because these species were not sampled in the Azores region with an active volcano. The Tagoro volcano area is much more similar to the Azores region. Raimundo et al. (2013) also studied metal and trace element concentrations in the Azores for the same species as in our study, *S. colias*, obtaining values of 0.32 mg/kg dw of Cr, 1.6 mg/kg dw of Cu, 21 mg/kg dw of Zn, 0.027 mg/kg dw of Cd, and 0.028 mg/kg dw of Pb. *S. colias* specimens from the Azores study showed higher concentrations for Cr, Zn, and Pb, with only Cd showing a higher concentration in our study.

The introduction of metals and trace elements into the marine ecosystem of the Canary Islands due to volcanic activity could have significant consequences for the fish species inhabiting the region. Metals and trace elements, released during volcanic eruptions, can be transported through water and accumulate in aquatic organisms along the food chain, including fish. Firstly, it is important to note that metals and trace elements can have toxic effects on living organisms, even at very low concentrations. These elements can affect the health and physiological functioning of fish in various ways. For example, they can interfere with enzyme function, induce oxidative stress, alter osmotic balance, and affect the nervous and endocrine systems of fish (Ali and Khan 2018; Cheung et al. 2021; Layton et al. 2020; Lobel 1981). Moreover, metals and trace elements can accumulate in fish tissues over time, leading to bioaccumulation in fish species and biomagnification along the food chain. This means that higher-level predators feeding on contaminated fish may accumulate even higher concentrations of these contaminants in their tissues. The effects of pollution by metals and trace elements on fish populations can be diverse. On one hand, there may be a decrease in the survival and reproduction of affected fish species. This could lead to a reduction in the abundance and diversity of fish in the marine ecosystem of the Canary Islands (Castro-González and Méndez-Armenta 2008; Company et al. 2010; Le Croizier et al. 2016; Nasyitah Sobihah et al. 2018; Playle et al. 1993). Furthermore, pollution by metals and trace elements can also affect human health through the consumption of contaminated fish. If fish accumulate hazardous concentrations of metals and trace elements, there is a risk that people consuming these fish may be exposed to toxic levels of contaminants, which can have adverse health effects such as neurological, reproductive, and carcinogenic problems. To mitigate the negative effects of pollution by metals and trace elements on the marine ecosystem of the Canary Islands, effective environmental management and control measures would be needed. This could include continuous monitoring of water quality and marine biota to detect and prevent excessive accumulation of contaminants, as well as the implementation of sustainable management practices to reduce emissions of contaminants into the environment. Additionally, it is crucial to educate the local population and fishermen about the risks associated with pollution by metals and trace elements in fish and to promote responsible fishing practices and safe fish consumption (Cordón Lagares et al. 2016; Cunningham et al. 2022; Pauly et al. 1998; Rousseau et al. 2019; Trathan et al. 2015; Yilanci et al. 2023).

Conclusions

Scomber colias Atlantic chub mackerel specimens from the area affected by the Tajogaite Volcano (La Palma) showed higher concentrations of all the metals and trace elements analyzed than those from the other study areas. This can be explained by the fact that in volcanic eruptions, through gases and lava, many compounds rich in these metals and trace elements are released into the environment. Moreover, it is also for this reason that the specimens from the area of influence of the Tagoro Volcano (El Hierro) showed the second highest concentration of the elements studied, although this volcanic process is in a state of degassing and only introduces metals and trace elements into the environment in gaseous form.

Comparisons with other studies underscored similar patterns of metal concentrations near volcanic regions, with higher levels observed in specimens from areas affected by volcanic activity compared to those from non-volcanic regions.

Overall, the introduction of metals and trace elements into the marine ecosystem of the Canary Islands due to volcanic activity poses significant implications for fish species. Effective environmental management and control measures are essential to mitigate the negative effects on both marine ecosystems and human health, necessitating continuous monitoring, sustainable management practices, and public education on safe fish consumption practices.

The Atlantic chub mackerel *S. colias* is shown to be a good bioindicator of natural pollution produced by volcanoes, whether in a gaseous or terrestrial state or those that emit lava directly into the marine environment.

Author contribution Enrique Lozano-Bilbao: data curation, formal analysis, writing original draft, writing review and editing, validation, software, and visualization; Indira Delgado-Suárez

José M. Lorenzo: writing review and editing, supervision, resources, and investigation

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Introduction: ELB, IDG, AJG, M&M: JML, JAG, DGW, IDS, SP, CR, ELB, AJG

Results: ELB, AJR, JML, JAG, SP, AH, AJG

Conclusion: ELB, IDS, AJR JML, JAG, CR, AH, AJG

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Data availability Data will be made available on request.

Declarations

Ethics approval All authors declare that the use of animals for this research complies with the requirements of the European legislation on the use of animals for experimentation. All the samples collected were provided by the fishermen in the fish markets, so these organisms were not slaughtered by the authors of this manuscript; therefore, we faithfully comply with the Code of Practice for Housing and Care of Animals Used in Scientific Procedures.

Consent to participate For the study, no animals had to be killed, so it is not applicable.

Consent for publication The authors consent the publication of this study.

Competing interests The authors declare no competing interests.

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