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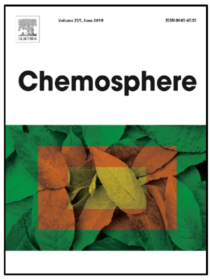

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Inferring trophic groups of fish in the Central-East Atlantic from eco-toxicological characterization

Enrique Lozano-Bilbao [a]*, Sabrina Clemente [a], José María Espinosa [b], Alba Jurado-Ruzafa [c], Gonzalo Lozano [a], Joana Raimundo [d], Arturo Hardisson [e], Carmen Rubio [e], Dailos González Weller [f], Sebastián Jiménez [c] & Ángel J. Gutiérrez [e]

[a] Departamento de Biología Animal y Edafología y Geología, Unidad Departamental de Ciencias Marinas, Universidad de La Laguna, 38206 La Laguna, Santa Cruz de Tenerife, Spain.
[b] Fundación del Sector Público Estatal Observatorio Ambiental Granadilla (Unidad Técnica), 38001 Santa Cruz de Tenerife, Spain.
[c] Instituto Español de Oceanografía. Centro Oceanográfico de Canarias, Vía Espaldón, Dársena Pesquera, 38180, Santa Cruz de Tenerife, Spain.
[d] IPMA - Portuguese Institute of Sea and Atmosphere, Rua Alfredo Magalhães Ramalho, 6, 1495-006 Lisboa, Portugal.
[e] Departamento de Obstetricia y Ginecología, Pediatría, Medicina Preventiva y Salud Pública, Toxicología, Medicina Legal y Forense y Parasitología, Universidad de La Laguna, 38200 La Laguna, Santa Cruz de Tenerife, Spain.
[f] Servicio Público Canario de Salud, Laboratorio Central, Santa Cruz de Tenerife, Spain.

*Corresponding author: lozaenr@gmail.com

Abstract

The marine organisms are exposed to great human-induced alterations due to the indiscriminate discharges into the sea, which is why the study of marine pollution is of great value for each ecosystem. Each organism bioaccumulates distantly the heavy metals and trace elements in its organism. Because of this it is possible to classify different groups of fish according to their feeding with the content of these metals. Ten fish species were grouped considering their trophic level and habitat ecology (benthic predators, herbivores, omnivores, pelagic predators and superpredator) and analyzed for its metal content. Statistically significant differences were found among all the fish groups, with the Superpredator group containing the highest concentrations in all metals, mainly Fe (103.751±92.151 mg/kg) and Al (28.908±21.221 mg/kg). Therefore, this study highlights that the selection of the species taking into account feeding and habitat partitioning must be carefully considered being crucial to identify fish groups as biological indicators of marine pollution.

Keywords: Heavy metals, trace elements, trophic level, ecosystem, feeding

Introduction

The Canary Islands are located off the northwest coast of Africa, with nearest point to the continent in the east being 100 km away and the furthest point in the west being 450 km away. Due to the volcanic origin, the islands are characterized by abrupt bathymetry, with sharp profiles and narrow shelves, especially in the western islands, that affects oceanographic conditions and the distribution of marine organisms (Landaeta et al., 2012; Coca et al., 2014; García-Mederos et al., 2015). The archipelagos far from the continental coasts form a nexus of union with other islands, however, little is still known about the dispersion mechanisms which led to the first colonization of these archipelagos (Rundell et al., 2004, Cowie and Holland, 2006).

In marine environments, fishing activities have been historically directed towards specific target species, in many cases leading to severe population declines or even extinctions that alter the equilibrium of the ecosystem (Fujiwara, 2012). Different fishing methods are usually used to catch different groups of species. For example, the most common fishing methods used in the Canary Archipelago are purse seine to catch small pelagic fish, trammel nets or fishing traps to catch demersal species, angling fishing targeting all kinds of small and medium-sized fish, trolling to catch medium or large pelagic species, also targeted by angling with live-bait -such as sand-smelts, anchovies or sardines, among others, etc. (Begg, Friedland and Pearce, 1999; Zyadah and Chouikhi, 1999; Carrera and Porteiro, 2003; Lleonart and Maynou, 2003; Marçalo *et al.*, 2006, 2013; Murta et al., 2008a; Fujiwara, 2012; Mateu, Montero and Carrassón, 2014; García-Mederos, Tuya and Tuset, 2015; Lucena Frédou *et al.*, 2016; Corral and Manrique de Lara, 2017; Afonso *et al.*, 2018; Pascual-Fernández *et al.*, 2018; Jurado-Ruzafa *et al.*, 2019).

Coastal and marine areas are integral and essential ecosystems of the Earth and are critical for global food security and for the economic well-being of nations, particularly in developing countries. There is growing concern about the direct or indirect introduction of pollutants into the marine environment. In recent years, marine ecosystems have been impacted by contaminants coming from diverse human-induced sources such as processing industries, agriculture, domestic waste, mining, as well as other sources of a natural origin. Nearly 70% of the pollution comes from terrestrial anthropogenic activities, whose domestic, industrial and agricultural waste products are eventually discharged into the coastal waters, usually by underwater discharges (Topcuo, 2003, Ruilian et al., 2008, Žvab Rožič et al., 2012; Fort et al., 2016; Lozano-Bilbao et al., 2018a). Some pollutants constitute a serious risk for the environment, since they are highly stable chemical substances which cannot be metabolized by living organisms, meaning that they are resistant to biodegradation processes. Therefore, a bioaccumulation phenomena and a multiplying effect on the concentration of these substances or elements occurs in the trophic level network.

Depending on their relative levels, the presence of heavy metals in different foods can be a serious health hazard. However, the macronutrient and micronutrient metals (or trace elements) many of these are required by the organisms for the proper functioning of biological systems. Even more, trace metals can have beneficial or harmful properties in plants, animals and humans depending on their concentration (Bustamante et al., 2016a, 2016b, Carravieri et al., 2014, Dorta et al., 2015; Hosono et al., 2011, Kalay et al., 1999, Lozano-Bilbao et al., 2018a, 2018b, 2018c, Raimundo et al., 2013, Hinkley, 2001).

The main goal of the present study was to explore the relationship between the metal content patterns from fish by trophic level group with ecological features, such as feeding habits and habitat selection.

Material and Methods

Biological samples

A total of 352 specimens from 10 fish species were used in the study: *Thunnus thynnus* (Linnaeus, 1758), *Sparisoma cretense* (Linnaeus, 1758), *Chelon labrosus* (Risso, 1827), *Sarpa salpa* (Linnaeus, 1758), *Diplodus sargus cadenati* de la Paz, Bauchot & Daget, 1974, *Mullus surmuletus* Linnaeus, 1758, *Serranus cabrilla* (Linnaeus, 1758), *Trachurus picturatus* (Bowdich, 1825), *Sardina pilchardus* (Walbaum, 1792) and *Scomber colias* Gmelin, 1789. All the samples were obtained from commercial landings of the small scale fishery in the Canary Islands (Fig. 1).

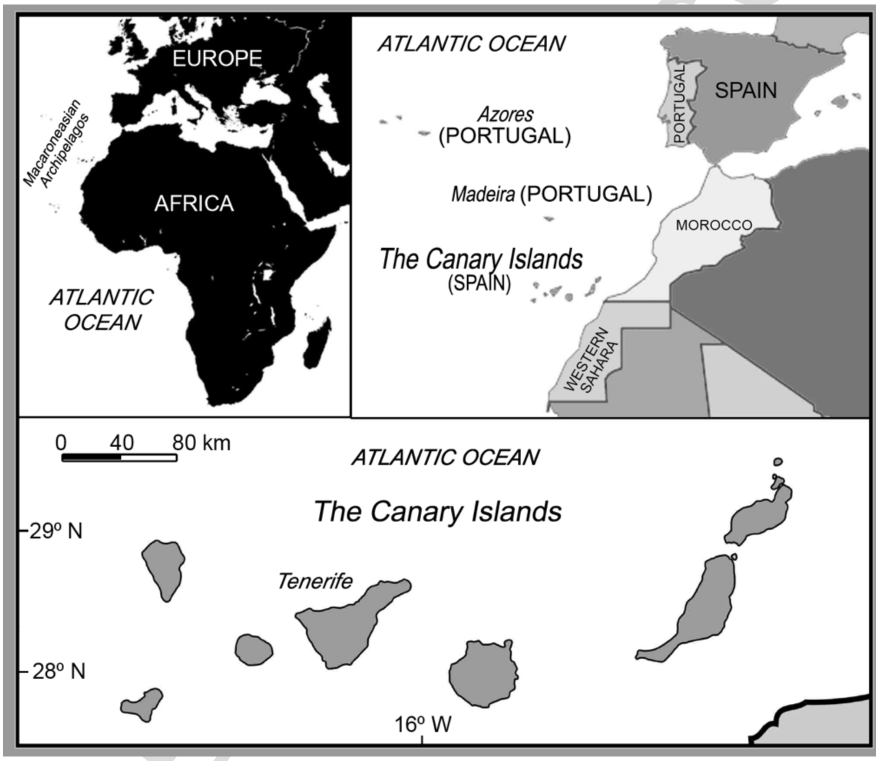

Figure 1: Map of the location Map of the locations of our study (Canary Islands, Spain)

Sample preparation

A muscle portion of approximately 5-10 g was dissected from the dorsal part of the body of each individual and preserved. The samples were dried in an oven at a temperature of 70 °C for 24 hours. They were then placed in a muffle furnace for 48 hours at 450±25ºC, until white ashes were obtained. If after this time the total mineralization of the samples had not been achieved, 65% HNO_3 was added to them in the fume hood and evaporated on a hot plate at 70-90 ºC. Once treated, they were incinerated again in a muffle furnace at 450 ± 25 ºC until the white ashes were obtained.

The white ashes were filtered with a solution of 1.5% HNO_3, made up to 25 ml for the subsequent determination of the metal content by optical atomic emission spectrometry with inductively coupled plasma (ICP-OES), to determine the concentration of the toxic heavy metals Al, Cd and Pb and the trace elements B, Cr, Cu, Fe, Li, Ni, V, Zn in the analyzed tissues.

Statistical analysis

The species were grouped depending on their feeding and habitat type as follows: Benthic predators: *M. surmuletus* and *S. cabrilla*; Omnivores: *S. cretense*, *D. sargus cadenati* and *C. labrosus*; Herbivores: *S. salpa*; Pelagic predators: *T. picturatus*, *S. pilchardus* and *S. colias*; Superpredator: *T. thynnus*. In order to investigate whether there were variations in the content and relative composition of the heavy metals and trace metals among the considered groups, a statistical analysis using a distance-based permutational multivariate analysis of variance (PERMANOVA) with Euclidean distances (Anderson and Braak, 2003) was performed. A one-way design was used with the fixed factor "feeding" with 5 levels of variation, depending on the type of feeding and habitat of the species analyzed. The variables included in the analysis were the concentration in mg/kg of the following metals: Al, B, Cd, Cr, Cu, Fe, Li, Ni, Pb, V and Zn. Relative dissimilarities among fish feeding habit groups were determined using a principal coordinate analysis (PCoA) in which the metals that best explained data variability were represented as vectors.

Finally, metals that best explained the variability of the data were explored by means of univariate assessments. One-way permutational analyses of variance with Euclidean distances of raw data were performed using the same design with the “feeding” factor as described above.

In all the analyses, 4999 permutations of exchangeable units and a posteriori pairwise comparisons were used to verify the differences between the levels of the significant factors (*p-value*<0.01) (Anderson, 2004). The statistical packages PRIMER 7 & PERMANOVA+v.1.0.1 were used for the statistical analyses.

Results

Table 1 shows the mean average concentrations of each metal for each group and their standard deviations in mg/kg wet weight.

Table 1. Mean average and standard deviations of the metal content by feeding/habitat group of fish (mg/kg, ww)

	Benthic predators	***Herbivores***	***Omnivores***	***Pelagic predators***	***Superpredator***
Al	2.723±2.378	2.736±2.257	3.136±4.166	5.626±3.373	28.908±21.221
B	0.099±0.054	0.267±0.154	0.188±0.105	0.154±0.07	0.441±0.275
Cd	0.006±0.005	0.003±0.006	0.002±0.003	0.081±0.157	0.054±0.037
Cr	0.072±0.032	0.105±0.077	0.159±0.171	0.226±0.413	0.923±1.053
Cu	0.770±0.286	0.498±0.303	0.546±0.347	1.223±0.541	1.919±2.151
Fe	4.177±2.213	5.309±2.369	5.681±4.315	11.861±6.212	103.751±92.151
Li	0.730±0.697	0.322±0.276	0.376±0.265	0.516±0.432	0.709±0.992
Ni	0.094±0.145	0.027±0.02	0.052±0.124	0.295±0.616	11.561±9.152
Pb	0.095±0.072	0.040±0.036	0.118±0.927	0.072±0.082	0.326±0.308
V	0.089±0.064	0.017±0.017	0.026±0.045	0.218±0.870	0.070±0.081
Zn	3.177±0.895	9.958±3.288	3.501±2.056	7.649±3.288	15.549±10.635

According to their type of feeding and habitat, the PERMANOVA revealed significant differences in the content and relative composition of heavy metals and trace metals among the groups of fish considered (Table 2).

Table 2. Results of the PERMANOVA, Main test. Results of the one-way PERMANOVA analysing the variation in the content of heavy metals and trace elements in the groups of fish with contrasting feeding habits and habitats.

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**

Feeding	4	75295	18824	87.268	0.0002*
Res	347	74848	215.7		
Total	351	1.5014E+05			

**p-value*<0.01

The *a posteriori* analyses, pairwise two by two, also showed significant differences in all the analyzed groups of fish (Table 3). These results were clearly visible in the PCoA analysis, which accounted for around the 89% of the total variability of the data (Fig. 2). The ordination of the samples showed a clear difference of the content of heavy metals in the Superpredator respect to the Benthic predators, omnivores and herbivores. These three groups appeared overlapped, meaning that they have similar heavy metals content. However, Pelagic predators presented a certain degree of overlap both with Superpredator samples and the 'Benthic predators-Omnivores-Herbivores' group. Benthic predators, Omnivores, appeared to have more similar heavy metals content, as can be seen by a smaller segregation between points belonging to each feeding group. A higher variability of data was especially observed in the case of omnivores, and samples belonging to this group were more grouped together with samples belonging to Benthic predators, Herbivores and, to a certain degree, with Pelagic predators. Metals that best explained the variability found in the data are represented as vectors in the PCoA, which showed a clear increasing pattern for Al, Fe, Ni, Cr, Cu, Zn, and B in the Superpredator group in comparison to the other groups, despite the great variability among samples in this feeding group.

Table 3. Results of the pairwise analysis. Results of pairwise tests examining the significant factor of 'Feeding' obtained in the one-way PERMANOVA analysing the variation in the content of heavy metals and trace elements in the groups of fish with contrasting feeding habits and habitats.

Groups	**t**	**P(perm)**
Pelagic predators vs. Benthic predators	7.9667	0.0002*
Pelagic predators vs. Omnivores	9.7478	0.0002*

Pelagic predators vs. Herbivores	6.1329	0.0002*
Pelagic predators vs. Superpredator	10.976	0.0002*
Benthic predators vs. Omnivores	3.415	0.0002*
Benthic predators vs. Herbivores	5.8315	0.0002*
Benthic predators vs. Superpredator	13.404	0.0002*
Omnivores vs. Herbivores	5.2564	0.0002*
Omnivores vs. Superpredator	14.365	0.0002*
Herbivorous vs. Superpredator	11.376	0.0002*

**p-value*<0.01

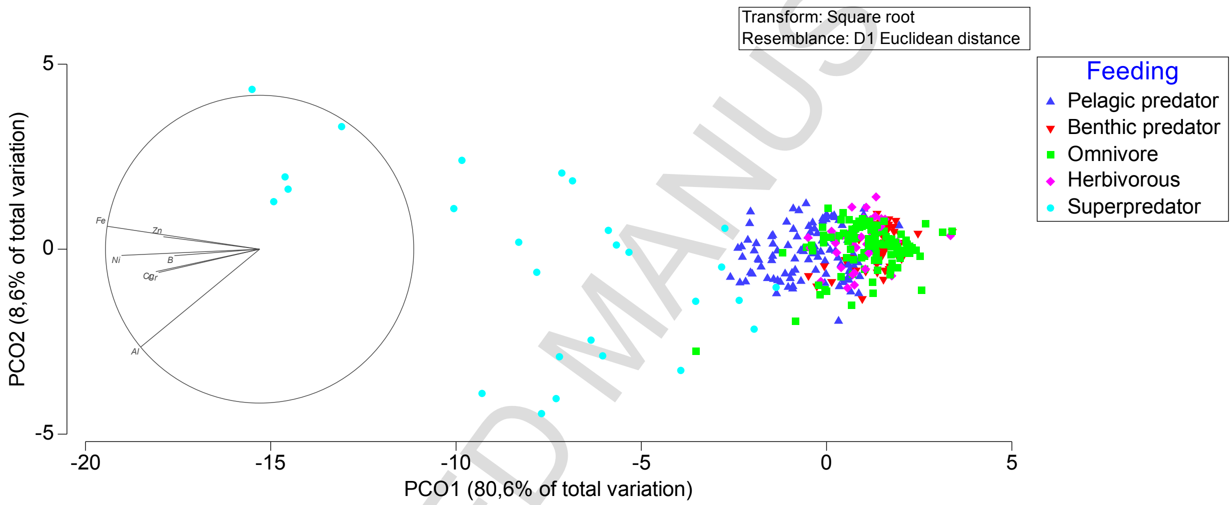

Figure 2. Principal coordinate analysis (PCoA) showing the first two axes (89.2% of variability), based on Euclidean distances of square-root-transformed data of heavy metal and trace element content in the groups of fish with contrasting feeding habits and habitats.

A second PCoA, excluding samples belonging to the Superpredator group was performed to better investigate the differences among the other feeding groups, which recorded more than 78% of the total data variability (Fig. 3). Iron (Fe), Cu, and Cd contents resulted higher in many of the samples of the Pelagic predators.

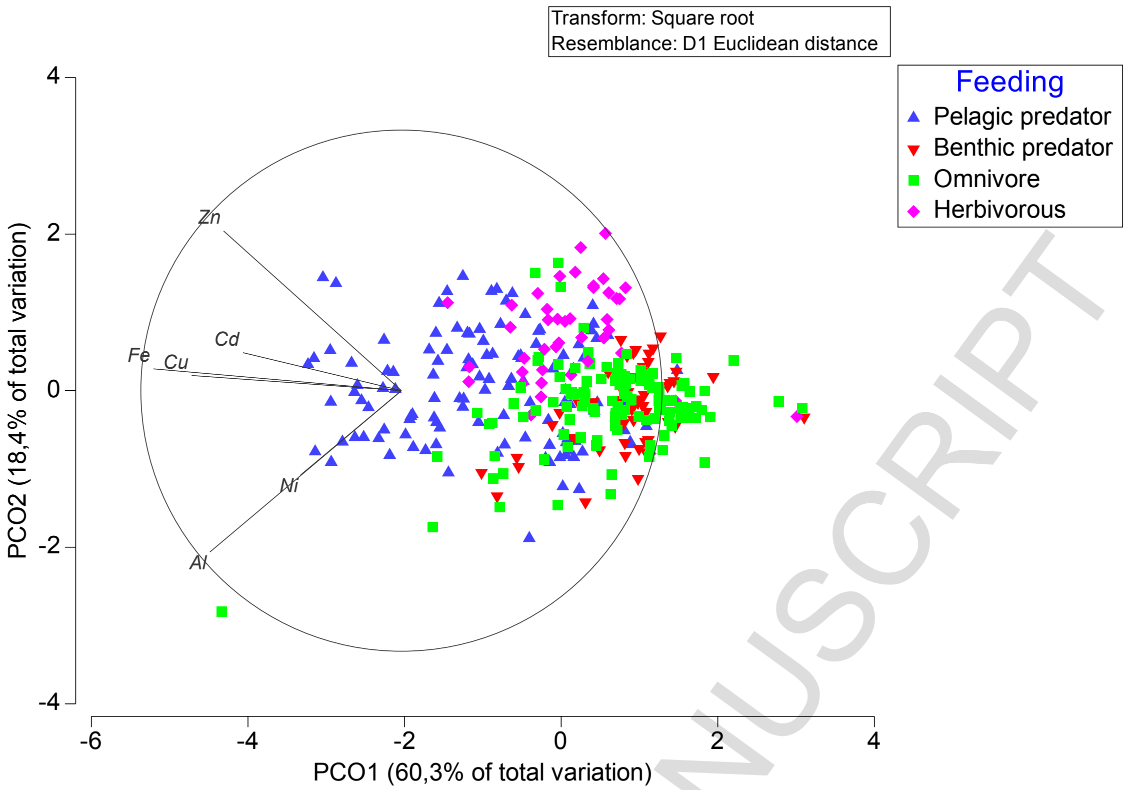

Figure 3. Principal coordinate analysis (PCoA) showing the first two axes (78.7% of variability), based on Euclidean distances of square-root-transformed data of the heavy metal and trace element content in the groups of fish groups contrasting feeding habits and habitats, excluding Superpredators to better see the differences between the other feeding groups.

The results of univariate permutational ANOVAs on metals that best explained data variability, such as Al, B, Cd, Cr, Cu, Fe, Ni and Zn (Fig. 2 and 3), showed a significant effect of the feeding group in all cases. Pairwise comparisons showed significant differences between the Superpredator group and the rest of the feeding groups in all the metals considered (Table 4), with the highest concentrations in the Superpredator group (Fig. 4). Herbivorous fish differed from Pelagic predators and Benthic predators in the content of most of the analysed metals, with the exception of Cr in the first comparison, and Al and Fe in the latter, in which no differences were detected (Table 4). The observed pattern of variation of such elements showed a significant increasing trend of concentrations of Al, Cd, Cu, Fe and Ni in Pelagic predators, and higher concentrations of Cd, Cr, Cu and Ni in Benthic predators, in comparison to Herbivores (Fig. 3). Herbivores showed significantly higher contents of B and Zn (Fig. 3). Pelagic and Benthic predators differed in the content of all metals except in Ni, with higher concentrations in Pelagic predators (Table 4, Fig. 4). When comparing Omnivores with Pelagic and Benthic predators, differences were found in most of the studied metals except for B and Cr in the first comparison, and Al and Zn in the second one (Table 4). Concentrations of Al, Cd, Cu, Fe, Ni and Zn in Pelagic predators resulted significantly higher than in Omnivores, but concentrations of Fe and Ni were higher in the latter (Fig. 4). Higher concentrations of Cd and Cu were found in Benthic predators in comparison to Omnivores, while B, Cr, Fe and Ni showed significantly higher concentrations in Omnivores (Fig. 4). Finally, the Omnivore and Herbivore groups resulted more similar in most of the studied variables and no differences in the concentrations of Al, Cr, Cu, Fe and Ni were found (Table 4, Fig. 3). On the contrary, the obtained concentrations of B and Zn were significantly higher in Herbivores than in Omnivores, while the content of Cd was significantly higher in Omnivores (Table 4, Fig. 4).

Table 4. Results of pairwise tests examining the significant factor of '*Feeding*' obtained in *o*ne-way ANOVAs analysing the variation in the content of the main heavy metals and trace elements in the groups of fish with contrasting feeding habits and habitats.

Pairwise comparisons	Al	B	Cd	Cr	Cu	Fe	Ni	Zn
Pelagic predators *vs.* Benthic predators	0.0002*	0.0002*	0.0002*	0.0018*	0.0002*	0.0002*	0.0184	0.0002*
Pelagic predators *vs.* Omnivores	0.0002*	0.0254	0.0002*	0.4928	0.0002*	0.0002*	0.0002*	0.0002*
Pelagic predators *vs.* Herbivores	0.0002*	0.0002*	0.0002*	0.1018	0.0002*	0.0002*	0.0004*	0.0006*
Pelagic predators *vs.* Superpredators	0.0002*	0.0002*	0.9544	0.0002*	0.0006*	0.0002*	0.0002*	0.0002*
Benthic predators *vs.* Omnivores	0.537	0.0002*	0.0002*	0.0004*	0.0002*	0.0434*	0.0028*	0.384
Benthic predators *vs.* Herbivores	0.9776	0.0002*	0.0002*	0.0012*	0.0002*	0.017	0.0002*	0.0002*
Benthic predators *vs.* Superpredators	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*
Omnivores *vs.*	0.5866	0.004*	0.0066*	0.063	0.4762	0.9542	0.0202	0.0002*

Herbivores								
Omnivores *vs.* Superpredators	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*
Herbivores, Superpredators	0.0002*	0.0034*	0.0002*	0.0002*	0.0002*	0.0002*	0.0002*	0.0058*
*$p < 0.01$								

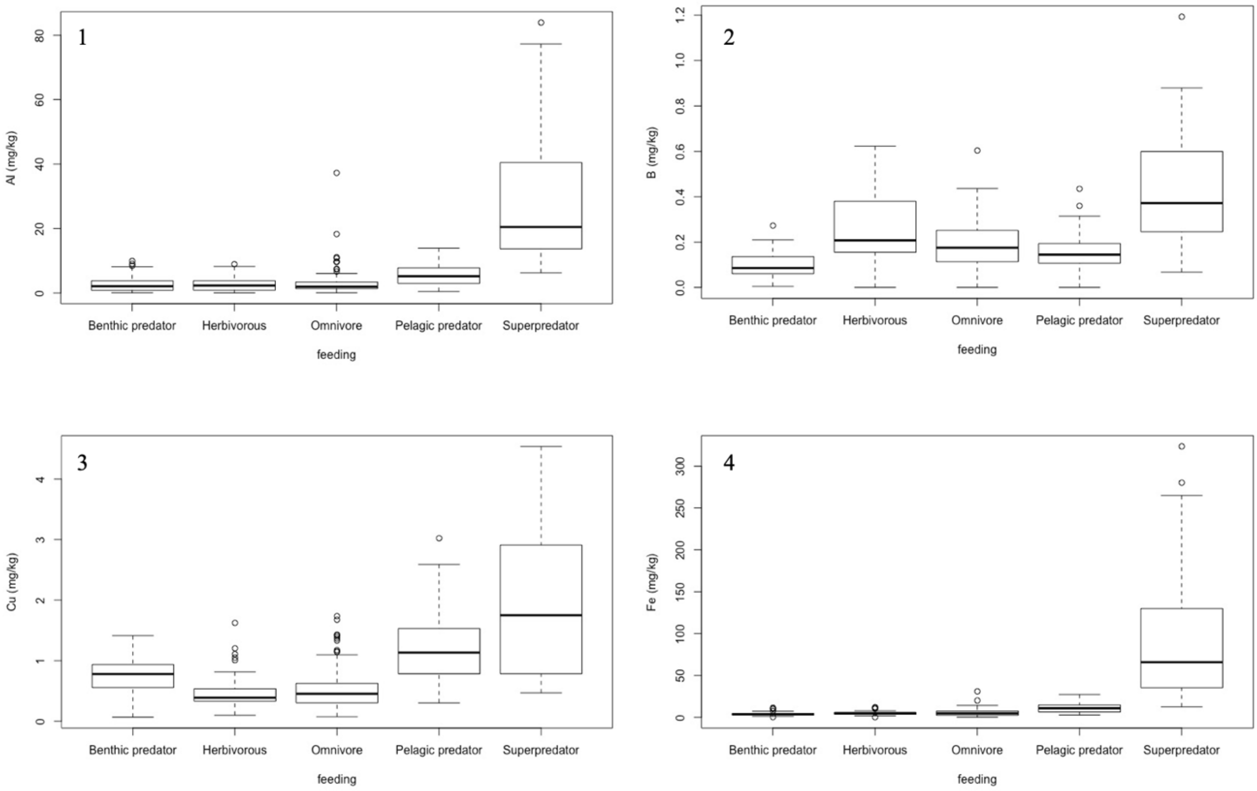

Figure 4 Boxplot graphs showing mean values for the metal contents, and minimum, maximum mg/kg (ww), for each considered feeding/habitat fish groups. 1: Al; 2: B; 3: Cu; 4: Fe.

Discussion

The results of the present study show the influence of ecological features in the concentration of metals accumulation in fish species, such as habitat use and feeding habits. Age, size and feeding habits of fish, as well as the amount of time spent in habitats with polluted waters during their life cycle, are known to influence metal contents in these organisms (Schuhmacher *et al.*, 1992; Kalay, Ay and Canli, 1999; Al-Yousuf, El-Shahawi and Al-Ghais, 2000; Canli and Atli, 2003). In this sense, the results show a great difference in the metal concentrations between the Superpredator group and the rest. The Atlantic bluefin tuna *T. thynnus* is the member of this group, which is the largest species in the study and which has the highest trophic level (Pauly et al., 1998, Walters, Pauly and Christensen, 1999). *T. thynnus* preys on many pelagic fish species , cephalopods and micronekton. The Atlantic bluefin tuna have a long life and reach a large size, what leads to a higher bioaccumulation of metal and trace element (Chase, 2002, Duffy et al., 2017, Goldsmith, Scheld and Graves, 2017, Mariani et al., 2017; Van Beveren et al., 2017). This explains the high concentrations of Al (28.908 mg/kg), Fe (103.751 mg/kg), Ni (11.561 mg/kg) and Zn (15.549 mg/kg) found here. Despite the fact that other metals such as Cu, Cr, B or Pb, were found in much lower levels, their concentrations in muscle of *T. thynnus* were significantly higher than in the other fish groups. The high concentration of Fe could be explained by the fact that tuna are highly migratory species with a high degree of muscle irrigation which enables them to travel long distances (Di Bella et al., 2015; Logan, Golet and Lutcavage, 2015; Api et al., 2018). Di Bella et al. (2015) studied the concentration of heavy metals and trace elements in adult *T. thynnus* specimens in the Mediterranean Sea, and found values of 18.623 mg/kg in Zn (similar to the 15.549 mg/kg reported in the present study), 0.306 mg/kg of Cu (much lower than the 1.919 mg/kg reported here), 0.012 mg/kg of Cd (value less than the 0.054 mg/kg found in the present study) and 0.01 mg/kg in Pb (also lower than the 0.326 mg/kg of Pb found here). The bioaccumulation occurring in this species is the result of their dietary exposure to metals when moving around in a wide variety of environments on their migratory routes (Amandè et al., 2010; Van Beveren et al., 2017). Therefore, despite the differences found, it is not possible to conclude that Mediterranean tunas have a lower concentration of heavy metals since this species travels thousands of kilometers during its life span (Arechavala-Lopez et al., 2015; Mourente, Quintero and Cañavate, 2015; Addis et al., 2016; Richardson et al., 2016)

The second group with higher concentration of most of the analyzed metals was the Pelagic predators, which includes *S. pilchardus*, *T. picturatus* and *S. colias*, with *S. pilchardus* being the smallest species and *S. colias* the largest, the latter even preys on the other two. All these species feed on plankton, micronekton and small pelagic fish (Alonso et al., 2018, Bode et al., 2018, Deudero and Alomar, 2015, Garrido et al., 2008, 2015, Marçalo et al., 2006; Morote et al., 2010). The Pelagic predator group presented high metal concentrations (5.626 mg/kg Al, 0.081 mg/kg Cd, 0.226 mg/kg Cr, 1.223 mg/kg Cu, 11.864 mg/kg Fe, 0.218 mg/kg). The high Fe content could be due to a higher musculature irrigation and, as in the Superpredator group, to the swimming capacity of these species. The high Al content found both in Pelagic predators and the Superpredator group seems to be a factor to be taken into account in pelagic species, which bioaccumulate this non-essential metal (Cimmaruta et al., 2008, Murta et al., 2008b, Lea et al., 2015; Brochier et al., 2018). Ngumbu et al. (2017) studied the metal content in *S. colias* from Liberia, and reported values of 0.426 mg/kg for Cu, 2.503 mg/kg for Fe and 5.021 mg/kg for Zn. Rubio et al. (2018) studied the metal content of *T. picturatus* in the Canary Islands and reported values of 1.51 mg/kg for Cu, 7.53 mg/kg for Fe and 4.69 mg/kg for Zn. Both studies showed lower concentrations of metals than in the present study. The intrinsic variability of the pelagic environment, even within the same region, as well as the numerous routes by which heavy metals can be introduced into the marine environment probably exacerbate the heterogeneity of heavy metal levels in pelagic fish tissues. (Canli and Atli, 2003; Licata *et al.*, 2005; Di Bella *et al.*, 2015).

The groups of Benthic predators and Omnivores had metal concentration profiles more similar to each other, probably due to the fact that the members of these groups have more similarities in their diet, containing different benthic components. The benthic species *S. cretense*, *D. sargus cadenati* and *C. labrosus* were included in the Omnivore group.

Among the three species, *D. sargus cadenati* presents the greatest carnivorous content in its diet, since it feeds on gastropods, sea urchins, amphipods, bivalves, decapods and a smaller degree on algae (Sala and Ballesteros, 1997; Lloret, 2003; Clemente et al., 2010; Figueiredo and Natário, 2013). *S. cretense* is a species associated with the vegetated rocky seabeds of the Canary Islands, including habitats dominated by macroalgae and seagrass meadows of *Cymodocea nodosa*. Its diet includes algae and various invertebrates such as crustaceans, molluscs and echinoids (Board, 1956, Clemente et al., 2010, Espino et al., 2015, Felline et al., 2017). In *C. labrosus*, as in the case of *S. cretense*, algae are equally important in the diet and they also feed on small invertebrates such as polychaetes, gastropods, bivalves and decapods (Santini et al., 2015; de Mendonça et al., 2018). Abdallah (2008) studied the metal content of *S. cretense* in Egypt, and reported values of 0.60 mg/kg for Cd, 1.2 mg/kg for Pb and 7.4 mg/kg for Zn. Carvalho et al. (2005) studied the metal content in *D. sargus cadenati* in Portugal, and found values of 0.96 mg/kg for Cr and 0.01 mg/kg for Pb. Cid et al. (2001) studied the metal content in *C. labrosus* from Portugal, finding values of 0.05 mg/kg for Pb, 0.006 mg/kg for Cd and 10.14 mg/kg for Zn. The Cd values obtained for the Omnivore group in the present study were much lower than the reported ones in the Mediterranean (Egypt), which were 0.002 mg/kg. The same occurred for Pb with a value of 0.118 mg/kg, but higher than those found in Portugal. Mediterranean waters is higher than in the Canary Islands, probably because this is a more closed and historically more contaminated sea.

The Benthic predator group includes *M. surmuletus* and *S. cabrilla*. The red mullet *M. surmuletus* inhabits muddy and sandy bottoms and the major components in its diet are crustaceans such as decapods, followed by amphipods and polychaetes (Levi and Francour, 2004; Labropoulou et al., 1997, Lionetto et al., 2003, Aguirre and Ciencies, 2005). *S. cabrilla* feeds on fish, small invertebrates such as crustaceans or mollusks and also sea urchins, and it usually inhabits rocky areas and algal seabeds (Sala, 1997, Morato, Santos and Andrade, 2000, Alós et al., 2011). Cid et al. (2001) studied the metal content of *M. surmuletus* from Portugal and found values of 0.02 mg/kg for Cd, 0.05 mg/kg for Pb and 6.67 mg/ kg for Zn. Roméo et al. (1999) studied the metal content of a species of the genus *Serranus* and reported values of 0.02 mg/kg for Cd and 0.3 mg/kg for Cu. Bearing in mind the values of the present study, Cd was much lower than 0.006 mg/kg although this was significantly higher in this group of Benthic predators than in other trophic levels such as Omnivores or Herbivores. However, Cu and Pb concentrations in the Canary Islands, which were 0.77 mg/kg and 0.095 mg/kg, respectively, were higher than in previous studies, which may be due to the increase in pollution in coastal areas, as the species of Herbivores and Omnivores analyzed here are found on the coast and this makes the bioaccumulation of heavy metals and trace elements higher than that reported in other studies from previous years (Verlecar et al., 2006; Vikas and Dwarakish, 2015). Differences in metal concentration may be related to many aspects such as habitat, fish mobility, diet, or to other characteristic behaviours of species (Henry *et al.*, 2004). The species included in this trophic group, especially *M. surmuletus,* have a noteworthy sediment-associated contamination due to the large amount of time spent in sediments where it mainly feeds. Similarly, previous studies have found higher mean values of Cd and Cu contents for flatfish also living in sedimentary sea bottoms (Zauke *et al.*, 1999; Green and Knutzen, 2003).

Finally, the Herbivore group was represented by only one species *S. sarpa*, which is a herbivorous species in its adult stage but carnivorous when young. As all the studied individuals were adults, it was characterized as an herbivore feeding on green and brown algae (Milazzo and Anastasi, 2006, Pagès et al., 2012, Gianni et al., 2017, 2018, Marco-Méndez et al., 2017). Signa et al. (2017) studied the metal content of *S. sarpa* in the

Mediterranean Sea, and reported values of 0.119 mg/kg for Cd, much higher than in the present study (0.003 mg/kg). In fact, the results found here on Herbivores were very similar to the Omnivore group in regard to the content of most of the analyzed metals and only higher levels of B and Zn were found. It is known that macroalgae bioaccumulate trace metals from the surrounding water column (Roberts, Johnston and Poore, 2008; Leal *et al.*, 2018). Rocky subtidal habitats of the Canary Islands are dominated by brown macroalgae and other temperate algal beds, which are particularly sensitive accumulators as their cell walls contain many sulphated polysaccharides for which metals display a high affinity. Indeed, recent studies have reported high concentrations of Zn (250 µg/g) in brown algae species, as well as Cu and Pb (Roberts, Johnston and Poore, 2008), which could further explain the bioaccumulation of these metals in herbivorous fish consumers. Surveys aiming to evaluate the presence of heavy metals in the marine biota, are currently implemented worldwide to identify indicators of marine pollution. Certain metals, such as Al, Cd, Hg and Pb are a matter of concern because of their high toxicity and tendency to bioaccumulate in the food web (Lionetto et al., 2003; Reguera et al., 2018; Catsiki and Strogyloudi, 1999). The present study has shown that in order to appropriately detect the presence of such elements in marine organisms, the selection of the species must be carefully considered having into account the feeding habits and habitat.

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Highlights

Ten fish species were grouped considering their trophic level

It is the top predators that have the highest metal concentration.

The groups of Benthic predators and Omnivores had metal concentration profiles more similar to each other