https://doi.org/10.29393/GM9-1CDMF30001

Gayana, Misc. 9(1-4): 3-16, 1988 ISSN 0374-7999

HEAVY METAL CONTENT AND DISTRIBUTION IN SURFACE SEDIMENTS FROM THREE AREAS OF CHILEAN COAST

CONTENIDO Y DISTRIBUCION DE METALES PESADOS EN SEDIMENTOS SUPERFICIALES DE TRES AREAS DE LA COSTA DE CHILE

M.A. Salamanca, L. Chuecas and F. Carrasco*

ABSTRACT

The concentration and distribution of Fe, Zn, Mn, Pb, Ni, Cd, Ag, As, and Hg were studied in surface sediments from three coastal locations (Concepción Bay, San Vicente Bay and Gulf of Arauco) of Chile. Cumulative curves were used to differentiate sediments populations. Background levels of the metals and Enrichment Factors (EF) were determined. A one way ANOVA to compare sediment concentrations between locations and correspondence analysis to establish the distribution pattern of metals, were used. The results reveal the occurrence of two sediment populations which are mixed in different proportions characterizing each of the three studied areas. The EF values show that, in general, the concentration of heavy metals in the sediments of the three investigated areas lies within the range of the natural levels except in locations near fishing ports (*i.e.*, Concepción and San Vicente Bays). Distribution patterns are discussed in relation to anthropogenic activities and natural processes. The metal content in sediments of the Gulf of Arauco correspond to the background levels, except for Hg and As.

KEYWORDS: Heavy metals, Sediments, Pollution, Embayments, Correspondence analysis, Chile.

RESUMEN

Se estudia la distribución y el contenido de Fe, Zn, Mn, Pb, Ni, Cd, Ag, As y Hg en sedimentos superficiales de tres localidades de la costa de Chile (Bahía Concepción, Bahía San Vicente y Golfo de Arauco). Se utilizaron curvas acumulativas para separar las poblaciones de sedimentos. Se determinaron Niveles Naturales y calcularon los correspondientes Factores de Enriquecimiento (FE). Las concentraciones de metales en sedimentos entre las localidades estudiadas fueron docimadas utilizando un Análisis de Varianza (ANOVA) de una entrada y los patrones de distribución fueron determinados mediante Análisis Factorial de Correspondencias. Los resultados indican la presencia de dos poblaciones de sedimentos mezcladas en diferentes proporciones, las que caracterizan cada una de las áreas estudiadas. El FE indica que en general las concentraciones de los metales estudiados están dentro del rango natural, excepto cerca de los puertos pesqueros en Bahía Concepción y Bahía San Vicente. En el Golfo de Arauco los niveles de metales corresponden a los naturales, excepto Hg y As. Se discute la distribución de los metales considerados en relación a la actividad antropogénica y procesos naturales.

PALABRAS CLAVES: Metales pesados, Sedimentos, Contaminación, Análisis de correspondencia, Chile.

INTRODUCTION

Marine sediments in coastal regions near large urban and industrial areas usually contain heavy metal concentrations several times higher than natural levels, indicating their anthropogenic origin (Chester and Voutsinou, 1981; Meyerson *et al.*, 1981).

Knowledge of concentrations and distribution of heavy metals in sediments permits i) an assessment of their availability in the marine ecosystem (Cosma *et al.*, 1982) since their inclusion in sediments represent an important

*Departamento de Oceanología. Universidad de Concepción. Casilla 2407, Concepción, Chile.

reservoir of metals from which they can eventually flow through the water sediment interface (Meyerson *et al.*, 1981) and ii) detection of pollution processes in aquatic systems (Fostner and Wittman, 1979).

The Concepción region (Fig. 1) is one of the most industrialized and progressive zones in Chile with a population of approximately 1.5 millions inhabitants, 60 per cent of whom live mainly near the cities of Concepción and Talcahuano. In this area, domestic and industrial wastes, both solid and liquid are discharged directly and indirectly (through the Bío-Bío and Andalién rivers and Estero Lenga) into the coastal waters without appropiate treatment (Fig. 1).

The work described here is part of a broad "base line study" carried out in April of 1979 in the littoral of Concepción region, which had as its main aim the analysis of sea water, sediments and a ribbed mussel (*Aulacomya ater*) samples for potential pollutants suchs as heavy metals, pesticides (DDT and DDE), petroleum hydrocarbons and detergents (Alkyl Benzene Sulphonate and Linear Alkyl Sulphonate).

No previous information was available on the presence of heavy metals in littoral sediments from Chile, except for Hg. Hoffman (1978) reported a concentration level of 0.045 ppm Hg in sediments of San Vicente Bay and very high concentration of Hg in stations near the site of discharge of a petrochemical plant into Estero Lenga (265.5 ppm Hg). Accordingly, the focus of this paper was to study the content and distribution of Fe, Zn, Cu, Mn, Pb, Ni, Cd, Ag, As and Hg in surface sediments from the littoral of Concepción region, and try to determine the degree to which these sediments could have been affected by heavy metal contamination.

STUDY AREA

The investigation was conducted in three different coastal environments of Concepción region, namely, Concepción Bay, San Vicente Bay and Gulf of Arauco (Fig. 2).

Concepción Bay (160 Km^2) is located at 36°40′ S.; 73°02′ W. Industrial wastes and sewage of 500,000 inhabitants of Tomé, Penco, Lirquén and Talcahuano cities are dumped into coastal waters. Urban and industrial wastes of Concepción City are also discharged into the bay through the waters of the Andalién river wich flows into the southeast area of the bay.

San Vicente Bay (11.5 Km^2) is located at 36°44′ S.; 73°09′ W. Urban wastes of 250,000 inhabitants of Talcahuano City as well as industrial wastes are directly discharged into this area. The unloading of crude oil and iron ore for and oil refinery and a steel mill plant, respectively, and the presence of harbour facilities result in a heavy ship traffic in the bay. Finally, wastes from the oil refinery are transported and discharged through Estero Lenga into the southern end of the bay.

The Gulf of Arauco (492.5 Km^2) is situated between 36°48′ S. and 73°10′ W. Small cities such as Coronel, Lota and Arauco (a total of 150,000 inhabitants) and a pulp and paper industry, a coal mine and lumber processing industries dump their wastes directly into the coastal waters. In addition, urban and industrial wastes of Concepción City are discharged into the Bío-Bío river which flows into the northern zone of the gulf.

METHODS AND MATERIALS

Sediment samples were collected at 9 stations in Concepción Bay, 6 stations in San Vicente Bay and 6 stations in Gulf of Arauco (see Fig. 2) using a 0.1 m^2 Smith-McIntyre grab entirely coated with epoxy paint. A teflon spatula was utilized to discard a thin surface layer of each sediment sample and to subsample the upper 5 cm of sediments. The subsamples were placed in precleaned heavy plastic bags and maintained at 0° C (packed in ice) and then transported to the laboratory within a few hours to be stored at −18°C until analysis. Three replicate aliquots from each subsample were analysed separately.

The metal concentration (except Hg) were measured according to the analytical procedures recommended by Anderson (1974). Briefly, 5 g of sample for the analysis of nonvolatile metals were dried to constant weight at 105°C for 48 hours. The dried samples were manually powdered and homogenized with a mortar and pestle. Prior to drying, rocks, shells and visible organisms were removed from the samples. The sediments were prepared for analysis by hot acid digestion (95°C for 5 hours) using a 1:1 mixture of concentrated HNO_3-HCl under continuous shaking. After cooling, 20 ml of distilled water were added and the digestate was filtered through acid washed Whatman N° 42 filter paper and dilute to a known volume.

The final solutions were analysed by atomic absorption using wavelengths and procedures recommended for a Perkin Elmer model 306 spectrophotometer, with an air-acetylene flame.

Total Hg was determined by routine cold vapour atomic absorption spectrometric procedure (Eganhouse *et al.*, 1978) using a Perkin Elmer model 303 spectrophotometer.

The concentration of trace metals were determined from the corresponding standard curves and measured as ppm on a dry weight basis. All acids used were Merck Suprapur; Super-Q water was used to prepare all standards by dilution of 1000 ppm stock solutions. The glassware and sample containers were pre-cleaned by soaking in a 6% HNO_3 solution for longer than 24 hours and, then rinsed with deionized-distilled water.

The metal content for each area were compared using a one way ANOVA and possible relationships between the different heavy metals were exploring using the correlation coefficient (r) of Pearson (Sokal and Rohlf, 1969). Sediment populations were determined by means of cumulative frequency probability plots (Sinclair, 1976). Correspondence analysis (Malgrem *et al.*, 1978; Flos, 1980) was used to establish possible relationships among the heavy metal concentration or distributional patterns in all the station of each location.

RESULTS

Heavy Metal Concentration

Table I shows the content of heavy metal in surface sediments from the three studied areas. The average concentration of Fe, Zn, Cu, Pb, Cd, and As are higher in Concepción Bay followed in a decreasing order by San Vicente Bay and Gulf of Arauco. However, the highest averages of Ag and Ni are observed in San Vicente Bay and the lowest in Gulf of Arauco. The highest values of Mn and Hg are found in San Vicente Bay and the lowest in Concepción Bay.

A comparison of the average concentration of each heavy metal calculated for the respective three areas reveals that such concentrations are different from each other for all the metals (ANOVA, $P < 0.05$; $F_c > F_t$) except for Zn (Table II). In addition, the comparison of the average concentrations on the basis of area pairs (Table III) indicates that the samples from Concepción Bay vs San Vicente Bay belong to different sediment populations, at least for Cu, Mn, Pb, Ni, Cd, As and Hg. Statistically Fe, Zn and Ag belong to the same sediment population. In Concepción Bay vs Gulf of Arauco only Mn and Hg concentrations belong to the same population. San Vicente Bay vs Gulf of Arauco present metal levels which are not significantly different, except Mn and Ni.

Tables IV, V and VI show the interelement correlation coefficients for heavy metals in sediments of Concepción Bay, San Vicente Bay and Gulf of Arauco, respectively. In Concepción Bay 20 of 45 possible correlations of metal concentrations are significant at 5% level. In San Vicente Bay 25 of 45 correlation are significant ($P<0.05$). The number of positive correlations between the two bays is similar; however, they do not correspond to the same metals. Finally, 32 of 45 possible correlations are significant for the Gulf of Arauco.

In San Vicente Bay the correlation matrix shows the formation of two groups of metals, *i.e.*, one group composed by Fe, Zn, Cu, Pb, Cd and As, and another group composed by Mn, Ni, Ag and Hg, indicating that Mn is negatively correlated with all the other metals. The Gulf of Arauco shows a higher and more uniform correlation than the other two areas investigated.

Background Levels and Enrichment Factors

In order to compare the degree of metal enrichment of sediment in the three studied areas it is necessary to estimate the background levels (BL) of each metal for the whole area. To obtain the BL the methodology suggested by Sinclair (1976) was followed for a small number of samples. The assessment of the number of sediment populations in the analysed samples is performed by plotting the individual cumulative frequencies of metal concentrations on a probability paper. This permits to select the lowest population as being the BL for the area. The geometric mean plus two standard deviations are considered the threshold that separate normal values from upper anomalous concentrations (Hawks and Webb, 1962).

The calculated BL of heavy metals for the investigated areas are presented in Table VII. Enrichment factors (EF = ratio between each concentration exceeding the upper limit of the BL for each geographic area and maximum BL) were calculated and are shown in Table VIII.

Correspondence analysis was used to establish possible relationships between stations on the basis of their heavy metal content. Figs. 3-a, 3-b and 3-c present the station grouping of Concepción Bay, San Vicente Bay and Gulf of Arauco, respectively, resulting from the multivariate analysis.

In Fig. 3-a the first two axes explain 93.32% of the variance found in Concepción Bay. Fig. 3-b shows the distribution of stations in San Vicente Bay on the two principal axes, which explain 97.71% of the total variance. Fig. 3-c presents the grouping of stations in the Gulf of Arauco, the first two axes explain 82.71% of total variance of concentration.

DISCUSSION

In Concepción Bay there is no clear formation of groups of correlated metals as compared to the other two studied areas. The Fe/metal correlation used to indicate common origen (Chen, 1976) reveals that Fe is negatively correlated only with Mn, suggesting different metal sources. On the other hand, Mn is negatively correlated with the majority of the studied metals, except Ni, Cu and Hg. Eighty percent of the bottom of Concepción Bay, including its central portion, is composed of black, reducing, H_2S-smelling sediments (Gallardo *et al.*, 1978). This could imply that the metals form stable metallic sulphides as solid phase, resulting in the strong correlation observed in the sediments.

In contrast to Concepción Bay, the sediments of San Vicente Bay are composed mainly of fine sand filling its central portion, and anoxic sediments are only present near the fishing port and outside the bay. However, water of low oxygen content (less than 1 ml/l) is observed within the bay from September to April (Universidad de Concepción, 1980) enhancing the possibility of the formation of metallic sulphides as solid phases. This might explain some of the observed correlations. In this bay the group composed by Fe, Zn, Cu, Pb, and As (correlation matrix) according to the Fe index reveals that this group has a common origen, although the detection of the groups of metals could also represent a mixture of two populations of sediments in the bay. The second group of metals could be determined by the effluents of a iron-steel mill plant, a petrochemical complex and sewage discharged into the bay.

In the case of the Gulf of Arauco Fe is positively correlated with all the metals, suggesting that they have a common origin conforming a sediment population which could be considered as the least influenced by potential sources of pollution. The latter could be explained by the fact that: i) the Gulf of Arauco presents the largest surface area compared to the other studied areas and ii) there are only three potential sources of pollution; inputs carried by the Bío-Bío river, a coal mine exploting off shore coal seams and a pulp mill plant.

The sediments in the Gulf of Arauco are composed mainly of sand, sandy mud and a small proportion of anoxic mud in the central-north area of the gulf (Alarcón, 1970). From September through May the bottom waters exhibit a very low dissolved oxygen content, less than 1 ml/l (Alarcón, 1970) which could determine and/or enhance the formation of metallic sulphides. This would particularly occur in the muds and sandy mud areas accounting for approximately 50% of the bottom of the gulf.

The results of the EF show that in Concepción Bay the most enriched metals are As and Cd in the 8 and 6, respectively, of the investigated sampling stations. Station 1 presents concentrations well above the maximum BL of Zn, Cu, Pb, Cd, As and Hg. The station is located near the fishing port suggesting the influence of anthropogenic activities. Fe, Mn, Ni and Ag show values that do not exceed the BL.

In addition, the correspondence analysis shows the presence of three groups of stations in Concepción Bay. The first group, comprised of stations 2, 4, 5, 6 and 7, is situated in the center of the bay and coincides with the presence of the black reducing (H_2S-smeling) muds, which might explain its distribution. Station 1 is not related with any other station indicating that the content of heavy metal could be influenced by the fishing port, where the highest EF values are found. The third group is composed by stations located outside the bay.

San Vicente Bay shows that the most enriched metals are Ni and Hg in 5 of the 6 sampled stations. Similarly to Concepción Bay the station that presents values exceeding the BL is station 8, located near the fishing facilities. Only Mn and Pb do not exceed the BL.

Effluents from an iron steel mill plant and a chloro-soda petrochemical complex are discharged into the bay and this could be a possible explanation for the observed mercury enrichment of its sediments. On the other hand, shipping activities related to the unloading of iron ore for the steel mill plant might also contribute to the enrichment of the heavy metal content in the sediments of the bay.

In San Vicente Bay the correspondence analysis show the presence of a group of stations comprised by stations 1, 2, 3 and 4 which are situated in the center of the bay, being related by their spatial proximity and similar water circulation. In fact, Silva *et al.* (1977) reported a counter clockwise gyre in the center of the bay. Station 8 resembles station 1 of Concepción Bay since it is also located near the fishing port presenting the highest EF values for all the metals (except Mn and Ni).

The Gulf of Arauco presents anomalous values only for As and Hg in the station 6 and 6-9, respectively. Station 9 is located at the mouth of the Bío-Bío river and station 6 is located in the central-north portion of the gulf. The high concentration of Hg could be related to the comparatively high content of the metal carried by the waters and sediments of the Bío-Bío river (INTEC, 1980), particularly during the winter time when the surface waters of the gulf are transported southward by the North wind.

In Gulf of Arauco, the correspondence analysis show the presence of a group comprised for stations 16, 18 and 21 which could be influenced by the wastes of a pulp and paper industry. The analysis separates station 9 located at the mouth of the Bío-Bío river, which makes it completely different to the others. Station 6 is located at the center of the gulf far from any source of pollution. Station 12 is located near Coronel city where there is coal mining activities which dump wastes directly into waters of the Gulf.

However, it is important to point out that the description of the grouping given above would rather correspond to potential pollution processes since the EF values reveal that the concentration of heavy metal of the Gulf of Arauco do not surpass their BL except As and Hg.

Tabla IX, reveals that the Gulf of Arauco contains the most natural sediment population. San Vicente Bay and Concepción Bay show various degrees of alteration, being more significant for San Vicente Bay. However, it is a fact that metal enrichment occurs in very localized areas (*i.e.*, near fishing facilities) except for Cd and As in Concepción Bay and Ni and Hg in San Vicente Bay.

CONCLUSIONS

In general, the results of the correlation matrix show that there is not a single process determining the distribution and/or enrichment of metals in the sediments of the three studied areas. From the analysis of the metal concentration on the probability paper, it can be concluded that the samples of metals are composed of two sediment populations (lower and upper populations), except Ni which is a mixture of three sediment populations (Table IX).

In general, the geometric mean of the lower population agrees very well with the geometric mean of Fe, Zn, Cu, Pb, Cd and Ag in the Gulf of Arauco. The geometric mean of Mn. As and Hg in Concepción Bay agrees with the geometric mean of the lower population. This would confirm that the metal content of the

Gulf of Arauco lies within the BL and that the sediments of San Vicente Bay and Concepción Bay would be the most altered, resembling the possible effect of anthropogenic inputs.

The mean concentrations of Fe, Zn, Cu, Mn, Pb, Ni, Cd, Ag and Hg can be compared with the values reported for some other areas of the world (Table X). The data indicate that the trace metal concentrations observed in marine sediments of the three studied areas are a little higher than the values detected for sediments of Pagassitikos Gulf (Chester and Voutsinou, 1981) and Kuwait (Anderlini *et al.*, 1982) which are regarded as unpolluted areas. On the other hand, the comparison of trace metal content between Chilean marine sediments and those of Thermaikos Gulf, regarded as "polluted sediments" by Chester and Voutsinou (1981) show lower concentrations in the Chilean system for some metals such as Cu, Cd.

Finally, the values obtained in this study present metal concentrations in sediments much lower than those found by Hershelman *et al.* (1981) in Palos Verdes Península, California, which were regarded as polluted, reflecting the effect of the discharge of treated municipal (domestic and industrial) water wastes via submarine outfall. In general, the situation of the investigated areas in the present study could be considered as intermediate relative to pollution processes compare with others areas in the world.

It is important to mention that the results presented in this paper should be regarded as preliminary, and that more detailed studies must be carried out in the future to establish the real effect of anthropogenic activities vs natural processes such as bioturbation and sedimentation rates that would explain the distribution and concentration could of heavy metals found in the sediments of the three investigated embayments.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. K. Cochran and Dr. M. Scranton of the Marine Science Research Center, State University of New York for critically reading the manuscript and to Prof. L. Balabanoff and Prof. Inés Gamé, Chemistry Department, University of Concepción for their assistance in the heavy metal determinations.

REFERENCES

ANDERLINI, V., O. MAHAMMAD, M. ZARBA, S. FOWLES and P. MIRAMAD. 1982. Trace metals in marine sediments of Kuwait. Bull. Envir. Contam. Toxicol. *28*: 75-80.

ANDERSON, J. 1974. A study of the digestion of sediments by the NO_3-H_2SO_4 and HNO_3-HCl procedures. Atomic Absorption Newsletter *13*: 1-31.

ALARCÓN, E.. 1970. Descripción preliminar de las condiciones oceanográficas del Golfo de Arauco. Investigación Pesquera, N° 13.

COSMA, B., R. FROCHE, F. BAFFI and A. DADOVE. 1982. Trace metals in sediments from Ligurian Coast, Italy. Mar. Pollut. Bull. *13*: 127-132.

CHEN, J. 1976. Heavy metal distribution in sediments from Chiai coastal area. Proc. Geol. Soc. China *19*: 78-86.

CHESTER, R. and F. VOTSINOU. 1981. The initial assessment of trace metal pollution in coastal sediments. Mar. Pollut. Bull. *12*: 84-91.

EGANHOUSE, R., YOUNG, D. and J. JOHNSON. 1978. Geochemistry of mercury in Palos Verdes sediments. Envir. Sci. Tech. *12*: 1151-1157.

FLOS, J. 1980. Ordination and Cluster analysis applied to oceanographical data Estuar. Coastal Mar. Sci. *11*: 393-406.

FORSTNER, V. and G. WITTMANN. 1979. Metal pollution in the aquatic environment. Springer-Verlag, Berlín, 486 pp.

GALLARDO, A., J. CASTILLO y A. YÁÑEZ. 1972. Algunas consideraciones preliminares sobre la ecología bentónica de los fondos sublitorales en la Bahía Concepción. Bol. Soc. Biol. Concep. *44*: 169-190.

HAWKS, H. and J. WEBB. 1962. Geochemistry in mineral exploration, Harper and Row, 415 pp.

HERSHELMAN, G., H. SHAFER, T. JAN and D. YOUNG. 1981. Metals in marine sediments near a large California municipal outfall. Mar. Pollut. Bull. *12*: 131-134.

HOFFMAN, W. 1978. Distribución del mercurio como contaminante en el agua, sedimentos y organismos del Estero Lenga y áreas adyacentes en la Bahía San Vicente (Concepción, Chile). Unpublished Thesis, Universidad de Concepción, 163 pp.

INSTITUTO DE INVESTIGACIONES TECNOLÓGICAS (INTEC). 1980. Evaluación del impacto causado por actividades industriales en el medio ambiente acuático. Diagnóstico preliminar. (Unpublished report), 127 pp.

Malgrem. B., C. Oviatt, R. Gerber and P. Jefries. 1978. Correspondence analysis: applications to biological oceanographical data Estuar. Coastal Mar. Sci. *6*: 429-431.

Meyerson, A., G. Luther III, J. Krajewski and R. Hires. 1981. Heavy metal distribution in Newark Bay sediments. Mar. Poll. Bull. *12*: 244-250.

Silva, J., R. Chaparro y H. Valdebenito. 1977. Algunos aspectos oceanográficos de la Bahía San Vicente. Unpublished Report. Universidad de Concepción, 14 pp.

Sinclair, A. 1976. Applications of probability graphs in mineral exploration. The Association of Exploration Geochemist. Special Volume N° 4. Richman printer Ltd., 95 pp.

Sokal, R.R. and J.F. Rohlf. 1969. Biometry-the principles and practice of statistics in biological research. W.H. Freeman, San Francisco, 776 pp.

Universidad de Concepción. 1980. Evaluación del grado de contaminación del litoral de la VIII Región. Vicerrectoría de Investigación. Universidad de Concepción (Unpublished report), 169 pp.

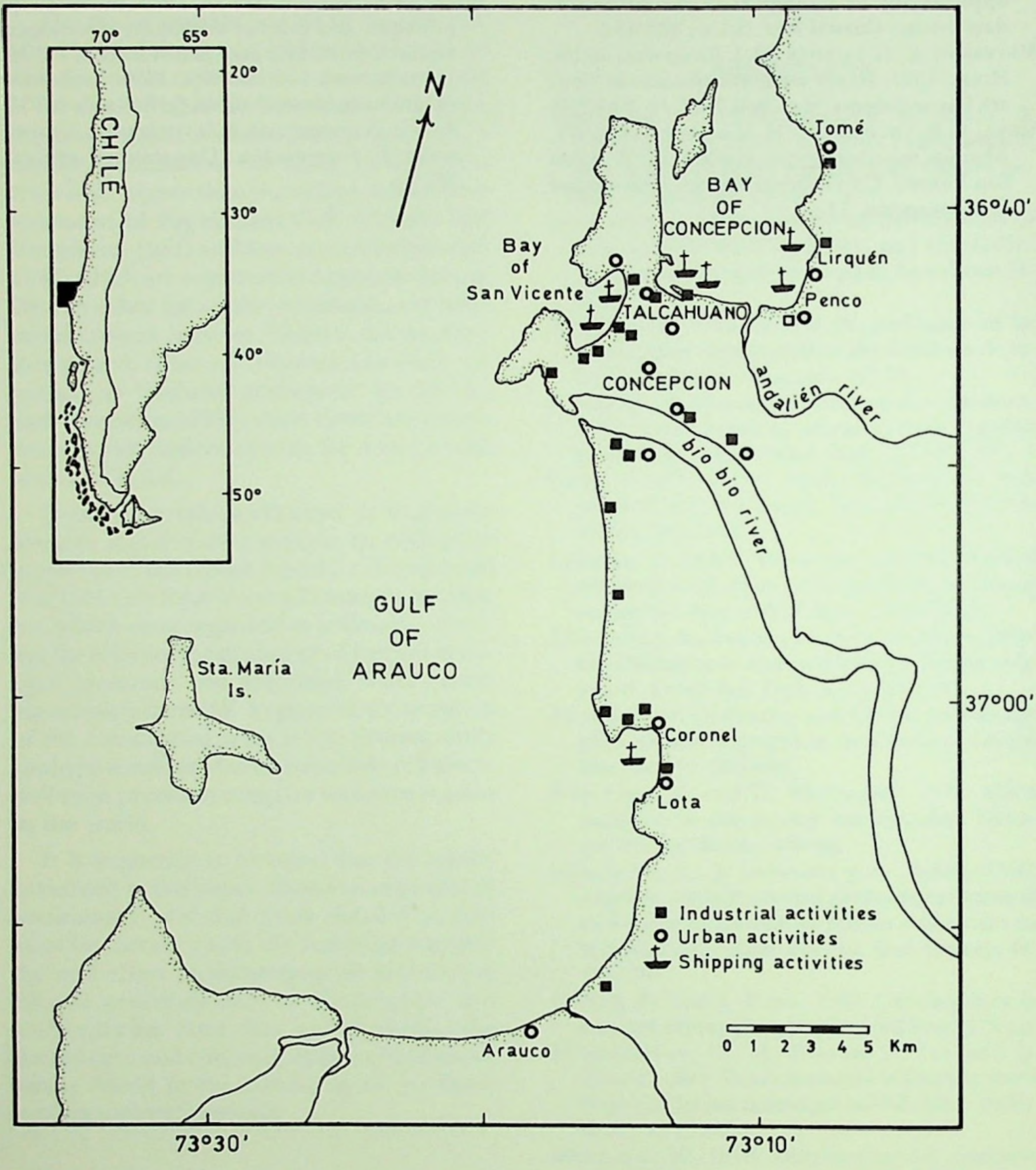

Fig. 1. Study area showing the industrial and shipping activities and major urban localities.

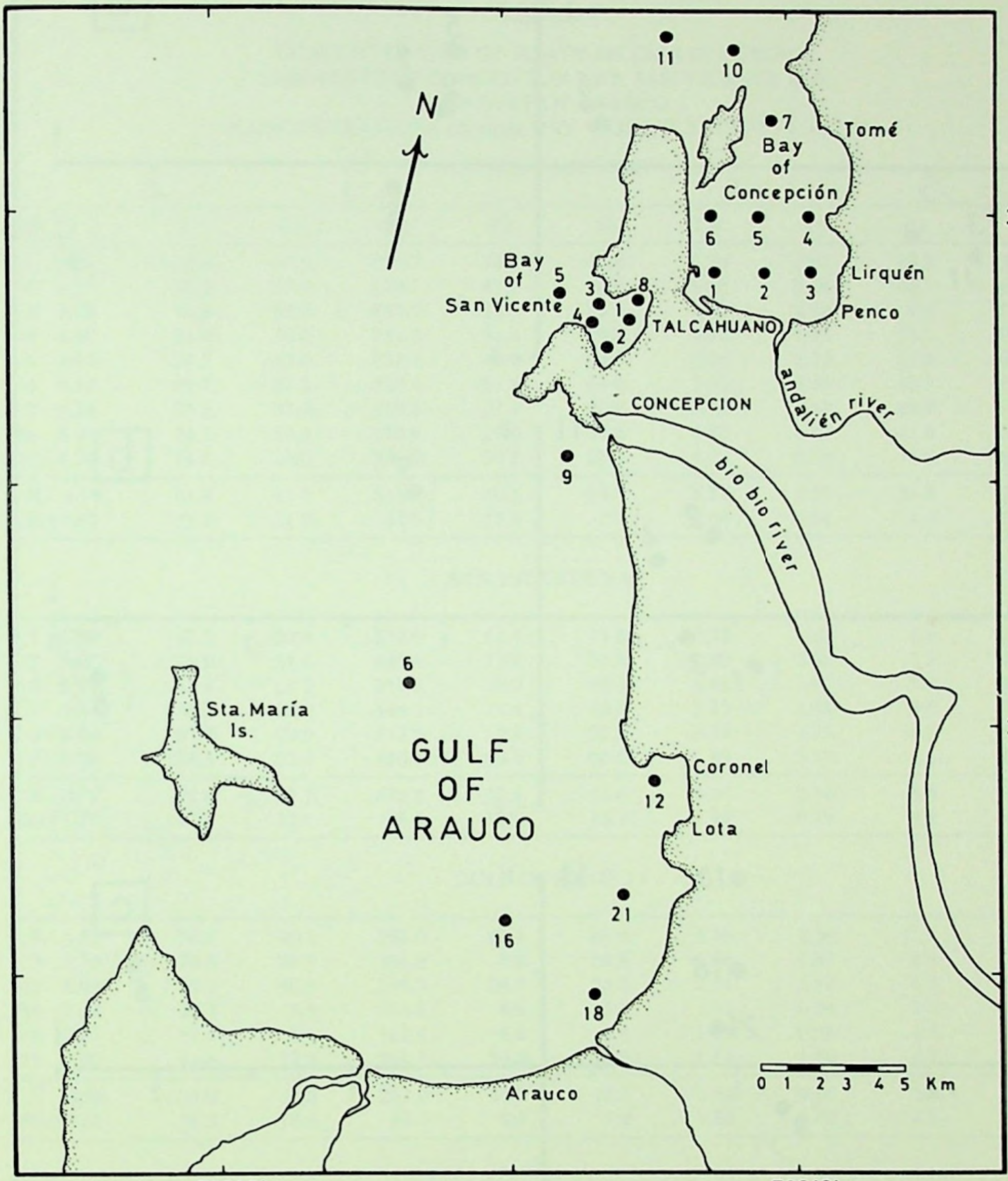

Fig. 2. Sampling stations in the three studied areas.

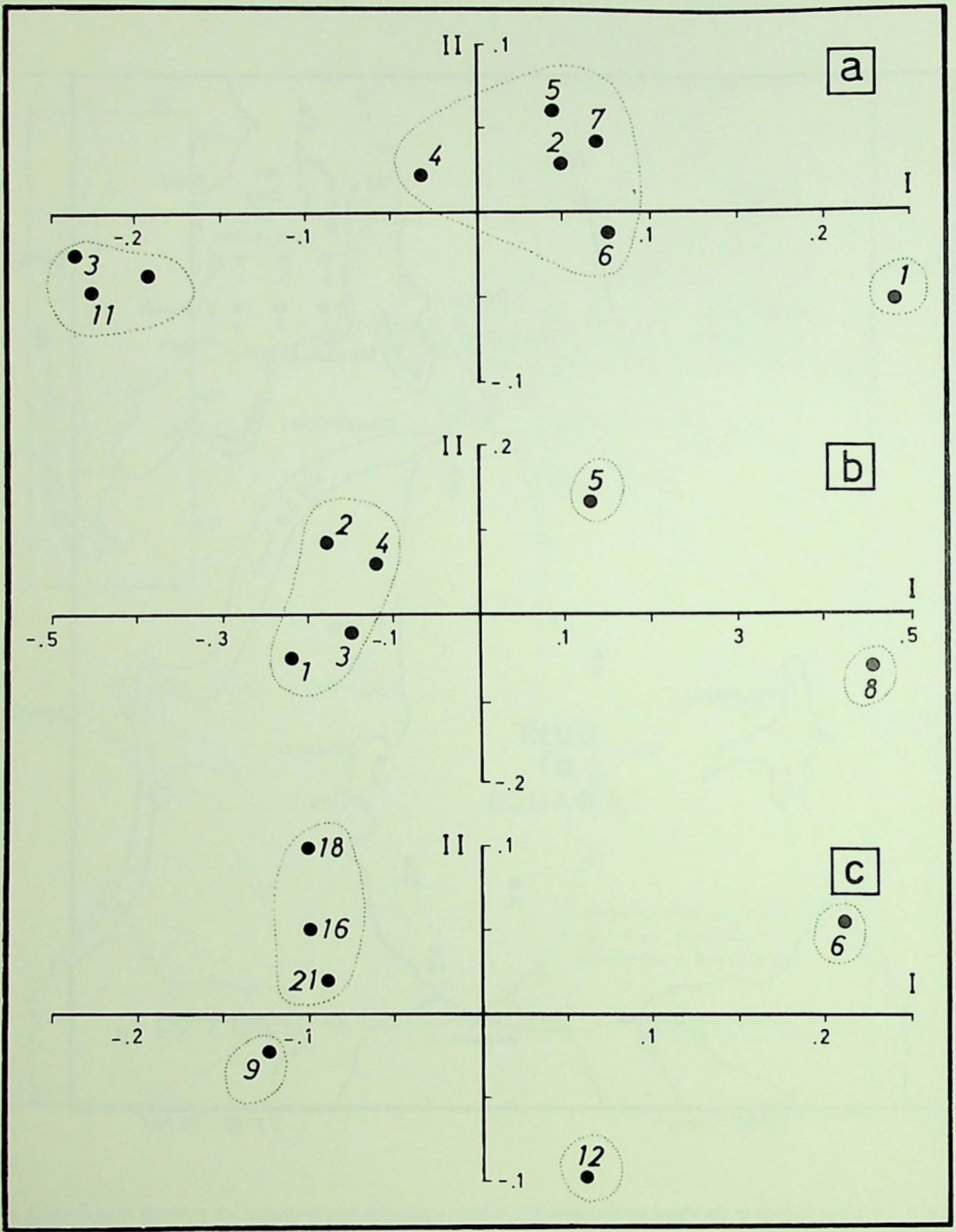

Fig. 3. Stations in the planes defined by the first two axes of correspondence analysis: a) Concepción Bay, b) San Vicente Bay, and c) Gulf of Arauco. Stations groups are encircled.

TABLE I

CONCENTRATION OF HEAVY METALS IN SURFACE SEDIMENTS OF CONCEPCION BAY, SAN VICENTE BAY AND GULF OF ARAUCO (CONCENTRATIONS IN ppm, DRY WEIGHT, EXCEPT FE IN %)

CONCEPCION BAY

Sta.	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg
1	3.98	142.6	67.9	220.7	74.2	24.0	7.76	2.81	22.3	0.36
2	4.17	92.9	37.0	220.7	42.8	20.0	5.58	2.50	20.7	0.11
3	3.73	70.6	32.0	283.3	20.0	24.0	4.12	2.18	9.5	0.12
4	4.30	91.6	39.5	241.3	31.4	24.8	8.87	1.90	15.7	0.14
5	4.43	91.7	42.0	233.1	40.0	24.0	9.16	2.50	21.8	0.13
6	4.42	92.7	47.3	212.0	51.3	24.0	7.04	2.50	15.7	0.18
7	4.74	95.2	37.0	228.8	51.4	28.0	5.86	2.50	19.6	0.20
10	3.92	74.1	30.5	270.6	20.0	21.0	3.82	1.87	11.8	0.11
11	3.95	74.6	35.6	300.8	30.2	23.1	4.24	2.18	11.8	0.09
$\bar{X}$	4.18	91.8	41.0	245.7	40.1	23.7	6.27	2.33	16.5	0.16
SD±	0.32	21.4	11.3	31.5	17.3	2.2	2.04	0.31	4.9	0.08

SAN VICENTE BAY

Sta.	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg
1	4.28	57.3	20.8	577.6	11.4	73.6	2.33	1.87	3.2	0.37
2	3.62	55.2	21.6	546.4	11.4	50.6	2.20	2.50	3.3	0.37
3	3.29	61.8	21.2	515.3	10.0	46.4	2.40	1.87	2.5	0.35
4	3.35	55.2	22.4	444.3	11.4	40.0	2.43	1.87	2.8	0.34
5	3.00	61.8	29.0	313.5	14.3	27.2	3.10	3.75	8.6	0.49
8	6.28	174.3	51.4	436.1	45.6	36.0	5.88	3.12	14.5	0.37
$\bar{X}$	3.97	77.6	27.7	472.2	17.4	45.6	3.06	2.50	5.8	0.38
SD±	1.21	47.5	12.0	95.6	13.9	15.9	1.42	0.79	4.8	0.05

GULF OF ARAUCO

Sta.	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg
6	4.20	76.8	40.3	269.5	22.4	24.0	4.70	2.50	15.4	0.39
9	3.26	76.8	23.0	364.9	8.6	24.8	2.08	1.87	3.9	0.17
12	3.60	63.1	46.3	330.3	20.0	24.8	2.64	1.87	4.7	0.46
16	2.20	31.1	8.1	154.0	8.6	9.6	1.35	0.94	2.0	0.10
18	2.27	31.1	6.1	162.4	8.6	8.8	1.05	0.94	4.8	0.12
21	2.96	44.4	17.9	260.7	20.0	12.8	1.64	1.25	4.1	0.26
$\bar{X}$	3.08	53.9	23.6	257.0	14.7	17.5	2.24	1.56	5.8	0.25
SD±	0.77	21.3	16.6	85.7	6.8	7.9	1.33	0.62	4.8	0.15

TABLE II

ANOVA OF METAL CONCENTRATION CONSIDERING THE THREE STUDIED AREAS

Metal	Fc	Ft
Fe	3.7	3.55
Zn	2.7	id.
Cu	3.6	id.
Mn	21.1	id.
Pb	7.5	id.
Ni	14.9	id.
Cd	12.0	id.
Ag	4.7	id.
As	12.8	id.
Hg	8.9	id.

Fc: Calculated factor; Ft: Tabulated factor P < 0.05.

TABLE III

ANOVA OF METAL CONCENTRATION CONSIDERING THE RELATION BETWEEN AREA PAIRS

Metal	Fc COB/SVB	Fc COB/GAR	Fc SVB/GAR
Fe	0.3*	14.9*	2.3**
Zn	0.6	11.4	1.2
Cu	4.7	5.9	0.2
Mn	44.7	0.1	16.8
Pb	7.2	11.5	0.2
Ni	17.2	5.1	15.1
Cd	11.2	18.0	1.1
Ag	0.3	10.0	5.2
As	18.0	18.0	0.0
Hg	33.0	2.3	4.2

COB: Concepción Bay; SVB: San Vicente Bay.
GAR: Gulf of Arauco.
Fc: Calculated factor; Ft: Tabulated factor.
*Ft = 4.67; **Ft = 4.96; P < 0.05.

Table IV

CONCEPCION BAY CORRELATION MATRIX

	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg
Fe	1.000	.184	.070	*−.649*	.400	.575	.533	.350	.576	.127
Zn		1.000	*.945*	*−.663*	*.924*	.178	.556	*.725*	*.759*	*.933*
Cu			1.000	−.570	*.888*	.145	.566	*.702*	.615	*.906*
Mn				1.000	*−.745*	−.145	*−.663*	*−.642*	*−.811*	−.558
Pb					1.000	.278	.504	*.872*	*.788*	*.871*
Ni						1.000	.305	.205	.126	.362
Cd							1.000	.339	*.681*	.412
Ag								1.000	*.757*	*.677*
As									1.000	.562
Hg										1.000

**Underlined* numbers are significant values (P < 0.05).

Table V

SAN VICENTE BAY CORRELATION MATRIX

	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg
Fe	1.000	*.921*	*.842*	.113	*.915*	.057	*.860*	.176	*.737*	−.255
Zn		1.000	*.973*	−.213	*.994*	−.318	*.982*	.410	*.895*	−.070
Cu			1.000	−.414	*.986*	−.471	*.997*	.592	*.969*	.135
Mn				1.000	−.264	*−.889*	−.383	*−.783*	−.553	*−.731*
Pb					1.000	−.343	*.989*	.469	*.923*	.011
Ni						1.000	−.438	*.690*	.536	−.473
Cd							1.000	.547	*.957*	.096
Ag								1.000	*.759*	*.841*
As									1.000	.373
Hg										1.000

**Underlined* numbers are significant values (P < 0.05).

Table VI

GULF OF ARAUCO CORRELATION MATRIX

	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg
Fe	1.000	*.901*	*.917*	*.718*	*.764*	*.885*	*.925*	*.976*	*.763*	*.850*
Zn		1.000	*.785*	*.867*	.437	*.964*	*.775*	*.946*	.571	.610
Cu			1.000	*.709*	*.759*	*.877*	*.803*	*.867*	.559	*.953*
Mn				1.000	.364	*.897*	.430	*.709*	.153	.572
Pb					1.000	.455	*.705*	.615	.618	*.890*
Ni						1.000	*.727*	*.914*	.462	.709
Cd							1.000	*.934*	*.912*	*.736*
Ag								1.000	*.775*	*.742*
As									1.000	.548
Hg										1.000

**Underlined* numbers are significant values ($P < 0.05$).

Table VII

CALCULATED BACKGROUND LEVEL (BL) OF HEAVY METALS FOR THE INVESTIGATED AREAS. (CONCENTRATIONS ARE EXPRESSED IN ppm, EXCEPT Fe EXPRESSED IN %)

Metal	Min.	Máx.	$\bar{X}$
Fe	0.66	5.65	2.34
Zn	13.82	103.61	42.66
Cu	8.52	50.61	15.13
Mn	93.10	741.60	242.70
Pb	8.48	47.98	14.10
Ni	4.67	30.20	10.70
Cd	0.86	5.30	1.99
Ag	0.40	3.45	1.41
As	1.81	10.87	3.63
Hg	0.03	0.34	0.11

Table VIII

ENRICHMENT FACTORS (EF) OF METALS IN SEDIMENTS OF THE THREE INVESTIGATED AREAS. PARENTHESES SHOW STATION NUMBERS

Area	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg
COB	—	1.4(1)	1.3(1)	—	1.5(1) 1.1(7) 1.1(6)	—	1.7(5) 1.6(4) 1.5(1) 1.3(6) 1.1(7) 1.1(2)	—	2.1(1) 2.0(5) 1.9(2) 1.8(7) 1.4(6) 1.1(10) 1.1(11)	1.1(1)
SVB	1.1(8)	1.7(8)	1.0(8)	—	—	2.4(1) 1.7(2) 1.5(3) 1.3(4) 1.2(8)	1.1(8)	1.1(5)	1.3(8)	1.4(5) 1.1(8) 1.1(2) 1.1(1) 1.0(3)
GAR	—	—	—	—	—	—	—	—	1.4(6)	1.4(9) 1.2(6)

*COB: Concepción Bay; SVB: San Vicente Bay; GAR: Gulf of Arauco.

Table IX

GEOMETRIC MEAN OF THE TWO SEDIMENT POPULATIONS PRESENT IN THE WHOLE AND THE THREE STUDIED AREAS. (CONCENTRATION EXPRESSED IN ppm, EXCEPT Fe EXPRESSED IN %)

Metal	LOP	UPP	COB	SVB	GAR
Fe	2.34	3.93	4.18	3.97	3.08
Zn	42.66	80.35	91.80	77.60	53.90
Cu	15.13	36.30	41.00	27.70	17.90
Mn	242.70	478.60	245.70	472.20	257.00
Pb	14.10	45.72	40.10	17.40	14.70
Ni*	10.70	24.0/48.9	23.70	45.60	17.50
Cd	1.99	5.37	6.27	3.06	2.24
Ag	1.41	2.45	2.33	2.50	1.56
As	3.63	14.79	16.50	5.80	5.80
Hg	0.11	0.35	0.16	0.38	0.25

LOP: Lower value population; UPP: upper value population; COB: Concepción Bay; SVB: San Vicente Bay; GAR: Gulf of Arauco.
*Ni is composed of a mixture of three populations.

Table X

COMPARISON BETWEEN AVERAGE HEAVY METAL CONCENTRATION IN MARINE SEDIMENTS FROM THE STUDIED AREAS AND OTHER ZONES OF THE WORLD (ppm, DRY MEIGHT, EXCEPT Fe in %)

Areas	Fe	Zn	Cu	Mn	Pb	Ni	Cd	Ag	As	Hg	References
Kuwait	1.5	45.0	21.0	410	23.0	97.0	1.5	—	—	—	Anderline *et al.*, 1982.
Pagassitikos Gulf	—	21.0	21.0	754	20.0	38.0	—	—	—	—	Chester and Voutsinou, 1981.
Thermoikos Gulf	—	107.0	24.0	966	82.0	70.0	—	—	—	—	Idem.
Palos Verdes Península	—	332.0	164.0	—	102.0	52.0	12.0	5.4	—	1.0	Hershelman *et al.*, 1981.
Concepción Bay	4.18	91.8	41.0	248	20.1	23.7	6.27	2.33	16.5	0.16	This paper.
San Vicente Bay	3.97	77.6	27.7	472	17.4	45.6	3.06	2.50	5.8	0.38	Idem.
Gulf of Arauco	3.08	53.9	23.6	257	14.7	17.5	2.24	1.56	5.8	0.25	Idem.

REGLAMENTO DE PUBLICACION DE GAYANA

1. La revista Gayana dedicada al distinguido naturalista francés Claudio Gay, es el órgano oficial de la Editorial de la Universidad de Concepción, Chile, para la publicación de resultados de investigaciones originales en el área de las Ciencias Naturales. Está compuesta de las series Botánica, Zoología y Miscelánea.
   Las dos primeras aparecen en la forma de un volumen anual compuesto por cuatro números; Gayana Miscelánea es aperiódica.
2. Gayana recibe trabajos realizados por académicos de la Universidad de Concepción y ocasionalmente los de otros investigadores nacionales o extranjeros de prestigio, elaborados según las normas del presente reglamento. La recepción es permanente.
3. Gayana acepta trabajos escritos en idioma español o inglés. La publicación en otros idiomas deberá ser consultada previamente al Director.
4. El manuscrito debe ser entregado en triplicado; una de las copias llevará las figuras originales.
5. El Director de la revista, asesorado por el Comité de Publicación, se reserva el derecho de aceptar o rechazar el manuscrito.
6. El manuscrito será enviado a pares para su revisión técnica.
7. La primera prueba de imprenta será enviada al autor principal para su corrección antes de la impresión definitiva. Si ello fuere imposible o dificultoso la corrección será realizada por el Comité de Publicación.
8. Los nombres científicos y las locuciones latinas serán las únicas que irán subrayadas en el texto. La primera vez que se cite un organismo deberá hacerse con su nombre científico completo (género, especie y autor).
9. Las medidas deberán ser expresadas en unidades del sistema métrico; si fuera necesario agregar medidas en otros sistemas, las abreviaturas correspondientes deben ser definidas en el texto. Decimales con coma, no punto (Ejemplo: 0,5).
10. Las citas en el texto deben incluir nombre del autor y año [Ejemplo: Smith, J.G. (1952)]. Si hay varios trabajos de un autor en un mismo año, se citará con una letra en secuencia adosada al año (1952a). Cuando hay más de dos autores todos los nombres serán citados en la primera mención [Ejemplo: Smith, J.G., P.J. Jones and W.E. Williams (1981); las referencias posteriores serán: Smith *et al.* (1981)].
11. La bibliografía incluirá todas y sólo las referencias citadas en el texto, dispuestas por orden alfabético del apellido del primer autor, sin número que la anteceda. La literatura botánica será citada según el B-P-H (Botánico-Periodicum-Huntianum) y la zoológica según el Style Manual of Biological Journals.
12. La nomenclatura de los trabajos botánicos y zoológicos se regirá por sus respectivos códigos.
13. Las ilustraciones y tablas deben ser adecuadas para, una vez reducidas, ocupar un ancho de 70 mm (una columna) o 150 mm (dos columnas) y una longitud no superior a 220 mm, incluido el espacio del texto explicativo.
14. Los dibujos deben ser de alto contraste y deben llevar una escala para facilitar la determinación del aumento.
15. Las figuras se numerarán en orden correlativo con números arábigos. Las tablas de igual modo con números romanos. Cada tabla debe llevar un título descriptivo en la parte superior.
16. Las fotografías se considerarán figuras para su numeración. Serán en blanco y negro, brillantes, de grano fino y buen contraste y deben ser acompañadas de una escala para la determinación del aumento.
17. En el reverso de las láminas originales se deberá indicar el nombre del autor, título del trabajo y número de las láminas.
18. Adjunto al manuscrito se entregarán en forma secuencial las explicaciones de cada una de las figuras.
19. El texto deberá contener: Título, título en inglés, nombre de los autores, dirección de los autores, Resumen, Abstract, Key Words, Introducción, Materiales y Métodos, Resultados, Discusión y Conclusiones, Agradecimientos y Bibliografía.
20. El título debe ir todo escrito en letra mayúscula y expresar el contenido real del trabajo. Si incluye un nombre genérico o específico se indicará el rango sistemático inmediatamente superior.
21. Si por alguna circunstancia especial el trabajo debe ser publicado en forma diferente a las disposiciones anteriores, el autor deberá exponer su petición al Director antes de enviarlo.

RECOMENDACIONES PARA PRESENTAR LOS MANUSCRITOS A GAYANA

1. INTRODUCCION, MATERIALES Y METODOS, RESULTADOS, DISCUSION, CONCLUSIONES, AGRADECIMIENTOS, BIBLIOGRAFIA, son títulos y se escribirán con MAYUSCULAS (AGRADECIMIENTOS).
2. Subtítulos: VERSALITA
3. Nombres de los géneros y de las especies (cuando encabezan un párrafo): ***negrita cursiva***
4. Nombres de sinónimos: *cursiva*
5. Nombres científicos en el texto: *cursiva*
6. Material estudiado: ALTA (8/10)
7. Indice de nombres científicos: ALTA (8/10)
8. En el índice de nombres científicos los nombres válidos en ***negrita cursiva*** y los sinónimos en *cursiva*.
9. Los tipos de letra se señalan en el original como sigue:

Tipo impreso	Nombre	En manuscrito
Un probable origen	Redonda	no se señala
VALD	ALTA	se subraya tres veces: VALD
MATERIAL ESTUDIADO	Versalitas	se subrayan dos veces: Material estudiado
a) crecen bien	baja	no se señala
Bromus berterianus	Cursiva	se subraya una vez: Bromus berterianus
BROMUS	ALTA CURSIVA	se subraya cuatro veces: BROMUS
Nota:	negrita	se subraya con una línea ondulada: Nota:
Bromus racemosus	negrita cursiva	se subraya dos veces, con una línea recta y otra ondulada: Bromus racemosus