Currents, civilization, or volcanism? Ostracodes as sentinels in a patchy environment: Kagoshima Bay, Japan

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ABSTRACT: The distribution of ostracod populations in Kagoshima Bay (South Kyushu, Japan) is analyzed with regard to environmental parameters. Topographic irregularity makes this elongated south-facing embayment amenable to subdivision into six different environments: Head, Margin, Slope, Basin, Mouth and Open Sea. The bay is under the influence of the Kuroshio Current, which enters from the east to flow northward along the west side of the Osumi Peninsula, and returns southward along the east side of the Satsuma Peninsula. A counterclockwise eddy current occurs in the widened central portion of the bay. The bay is in an area of andesitic volcanism centered in Mt. Sakurajima, an active volcano that rises from the water to separate the Bay Head area from the rest. The biocenotic indices such as abundance and diversity decrease from the Mouth of the bay towards the Basin and Head environments. On the other hand, volcanic ash and domestic input provide nutrients that are favorable to the ostracod biocenoses. The relative frequencies of species throughout the bay show that different environments are characterized by different assemblages. Correspondence analysis (CA) shows how ostracod distribution is influenced by the quality and structure of water masses such as dissolved oxygen content, salinity, anthropic pollution, and volcanically induced changes in pH.

INTRODUCTION

Ostracods are known to be sensitive indicators of many separate factors of their environment such as salinity, oxygen levels, substrate, depth and so on. In submarine volcanic environments, studies of the distribution of benthonic microfaunas has mainly concerned foraminifera, particularly in regard to studies of the effects of eruptions on benthic microfauna (Cita and Podenzani 1980; Finger and Lipps 1981; Oki 1989; Hess and Kuhnt 1996). The studies by Finger and Lipps and by Oki also observe the effects of other environmental parameters such as physiography, turbidity, water mass circulation, bathymetry and human pollution on the distribution of foraminiferal populations in two active volcanic calderas, Deception Island (Antarctica) and Kagoshima Bay (Pacific coast of Japan).

As far as we know, the influence of recent submarine volcanism on ostracod assemblages has never been studied. In this study, we evaluate the effects of activity in Sakurajima Volcano on the distribution of ostracod species in Kagoshima Bay. We also take into consideration the human pollution, the salinity and the water masses circulation inside the Bay.

GEOLOGIC SETTING AND PHYSIOGRAPHY OF THE STUDY AREA

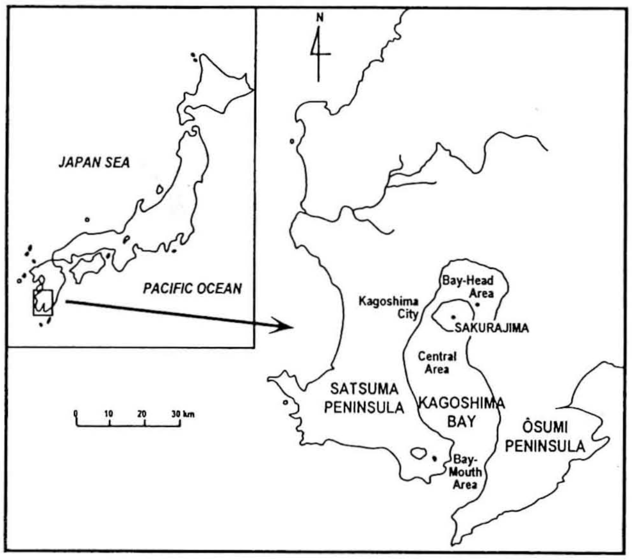
Kagoshima Bay (Kagoshima Prefecture) is located in the southern part of Kyushu, Japan (text-fig. 1). The bay, which lies between the Satsuma and Osumi Peninsulas, is a narrow, elongate body with a length of about 75km on a north-south axis and a width of about 25km, and opens southward. The maximum depth, about 230m (Oki 1989), occurs in the central part of the bay.

Kagoshima Bay is in a geological setting of Pliocene to Quaternary volcanics overling a basement of pre-Miocene Shimanto Complex and Miocene granites. Eruptions of mainly andesitic pyroclastics and lavas have been frequent from early Pliocene to the present. According to Matumoto (1943), Kagoshima Bay is genetically related to the formation of two calderas: Aira Caldera, in the bay head area, and Ata Caldera at the mouth of the bay (text-fig. 1). The presently active Sakurajima Volcano is situated on the south rim of the Aira Caldera, and has divided Kagoshima Bay into two areas since the eruption of 1914, during which thick flows of lava filled the channel between Sakurajima Island and the Osumi Peninsula (text-fig. 1-2). Sakurajima is one of the most active volcanoes in the world, and regularly erupts into the bay and onto the surrounding areas. The eruptions influence not only seawater characteristics but also the distribution patterns of benthonic foraminifers (Oki 1989) and ostracods.

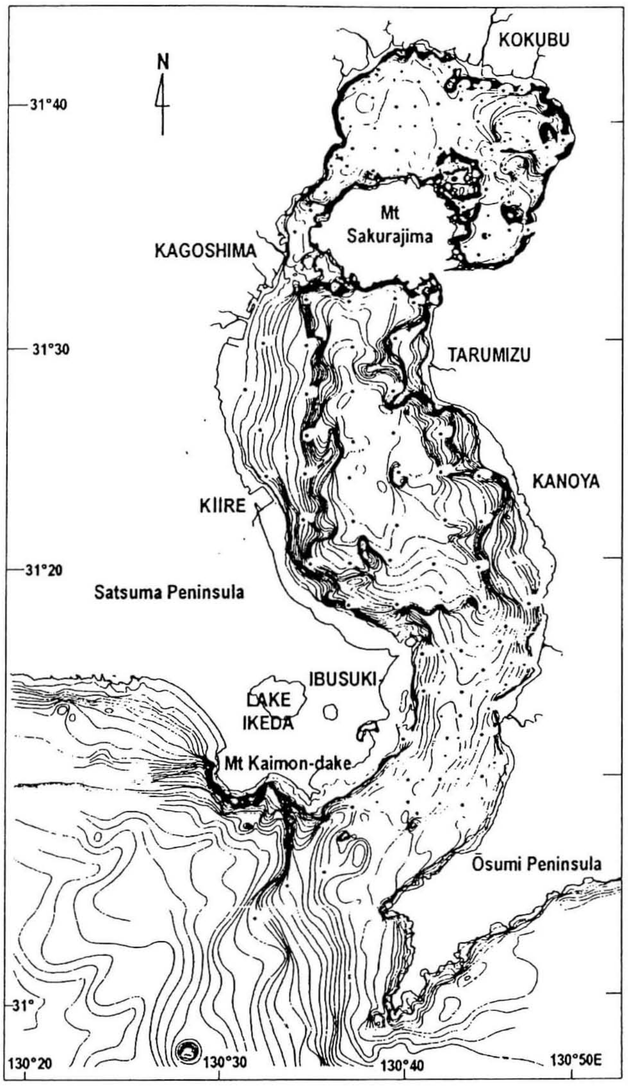
The bathymetric features of Kagoshima Bay allow us to divide it into three areas (Oki and Hayasaka 1983 and text-fig. 3).

The bay mouth area (called Bay Mouth in the text) is a channel with a quite constant width and a maximum depth of about 100m. Hydrothermal vents have been discovered on its west border, off Ibusuki.

The central area of the bay represents a basin-like topography about 230m deep; text-figure 2 shows clearly that this basin is fringed with a shelf limited by the 100m isobath (Margin in the text). The flat bottom, gently deepening from south to north (Basin in the text), is separated from the margin with a steeper slope which completely encircles it.



TEXT-FIGURE1
Index maps showing the location of the study area.



TEXT-FIGURE 2
Bathymetric map of Kagoshima Bay (after Oki 1989).

The bay head area (Bay Head in the text), north of Sakurajima Island, is separated from the basin by a narrow channel that shapes the base of the Sakurajima Volcano. The topography of this part is irregular. The bottom is flat in the western half and uneven in the east, where hydrothermal vents are known.

We describe the distribution of ostracods in the environments of Open Sea, Bay Mouth, Margin, Slope, Basin and Bay Head (text-fig. 3).

In Kagoshima Bay, water temperature decreases with depth and it is quite stable at 14 to 18°C throughout the year at depths below 150m. The water temperature at 100m in the central bay and the bay head areas is around 20°C in summer and autumn, with a slight decline in winter and spring. The temperature in water shallower than 75m, however, shows rather large seasonal fluctuations (14.2 to 30.2°C), though with somewhat less variation in the Bay Mouth due to ocean influences (Oki 1989).

The salinity of the water tends to decrease from the Bay Mouth (34.0 - 34.9 g/l in winter, 31.2-34.0 g/l in summer) to the Bay Head (33.0 - 34.3 g/l in winter, 23.3 - 32.7 g/l in summer). Nevertheless, the difference in salinity between the three areas of the bay is very slight. Although the salinity tends to decrease towards the Bay Head in winter, the values as a whole are not so different from those of the Open Sea (Oki 1989).

The distribution patterns of the surface temperature, salinity, transparency, submarine topography and bottom sediments (Sakurai and Maeda 1980; Oki and Hayasaka 1983; Oki 1989) demonstrate the presence of surface currents in the central and the southern areas of Kagoshima Bay and a stagnant water mass at depth in the central area. Based on these data, Oki (1989) identified five local water masses as described below (text-fig. 4).

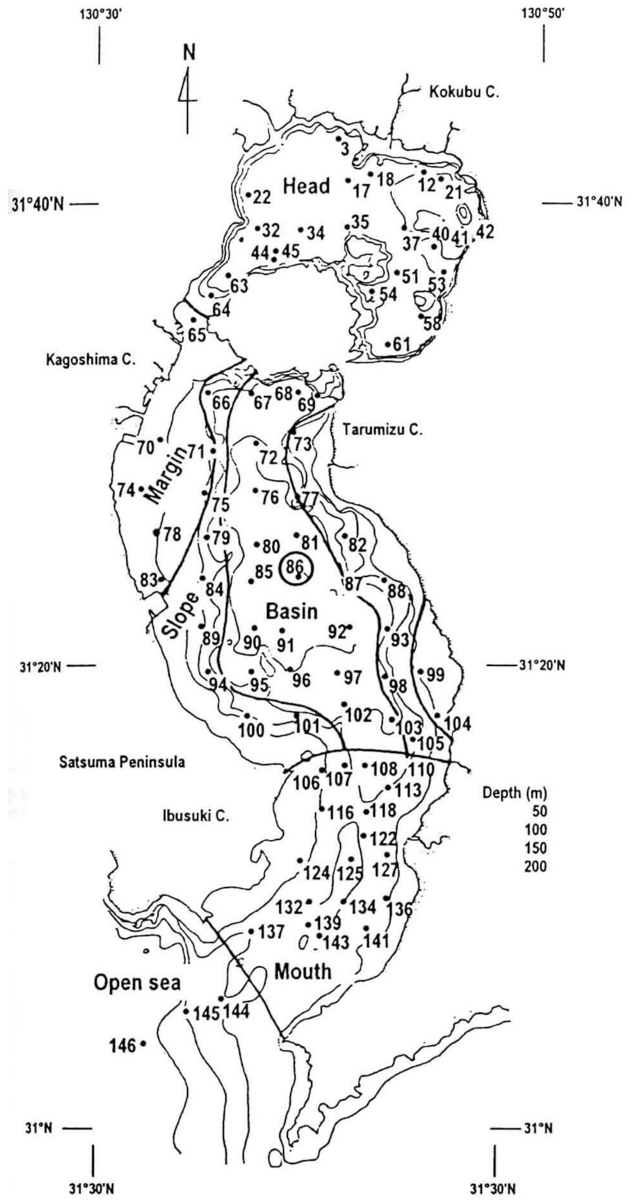
Water mass a in Kagoshima Bay is equivalent to the open-sea water, and is formed by a branch of the Kuroshio Current which enters the Bay along the west coast of the Osumi Peninsula, crosses the Bay in the northern part of the central area and flows back south against east coast of the Satsuma Peninsula. A counterclockwise current stream is assumed to occur at the northern margin of the central area. A branch of this water mass enters the Bay Head through the Sakurajima Passage.

Water mass c, consisting of low-salinity water collected in the embayment from runoff, flows southward along the east coast of the Satsuma Peninsula. This current is diverted by a reclaimed land area off the coast of Kiire-cho that projects into the sea, creating a very strong bottom current. A branch of water mass c crosses the Bay in the southern part of the basin area and flows back up against the Osumi Peninsula.

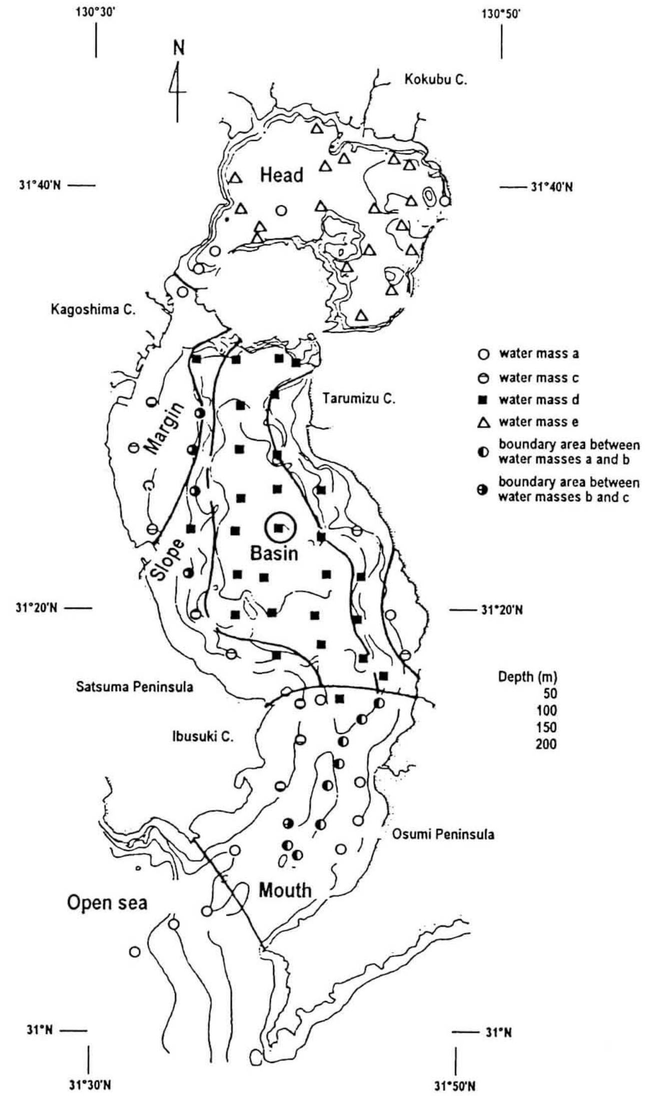
Two stagnant water masses, b and d, are confined to in the deepest part of the Central and Mouth areas.

Water mass e is found in the isolated northwestern and eastern parts of the Bay Head area, and is heavily influenced by discharge from hydrothermal vents.

These water masses change in size with the seasons. The area boundary between two water masses is not stable throughout the



TEXT-FIGURE 3
Topographic subdivisions of Kagoshima Bay showing six main environments. Points with numbers indicate sampling sites.



TEXT-FIGURE 4
Influence of water masses circulation on sampling sites.

year. The routes of the water masses pass through different areas of Kagoshima Bay (text-fig. 4). As a consequence of variations in their trajectories and the occurrence of obstacles, strong currents occur in the Bay.

MATERIAL AND METHODS

Sampling

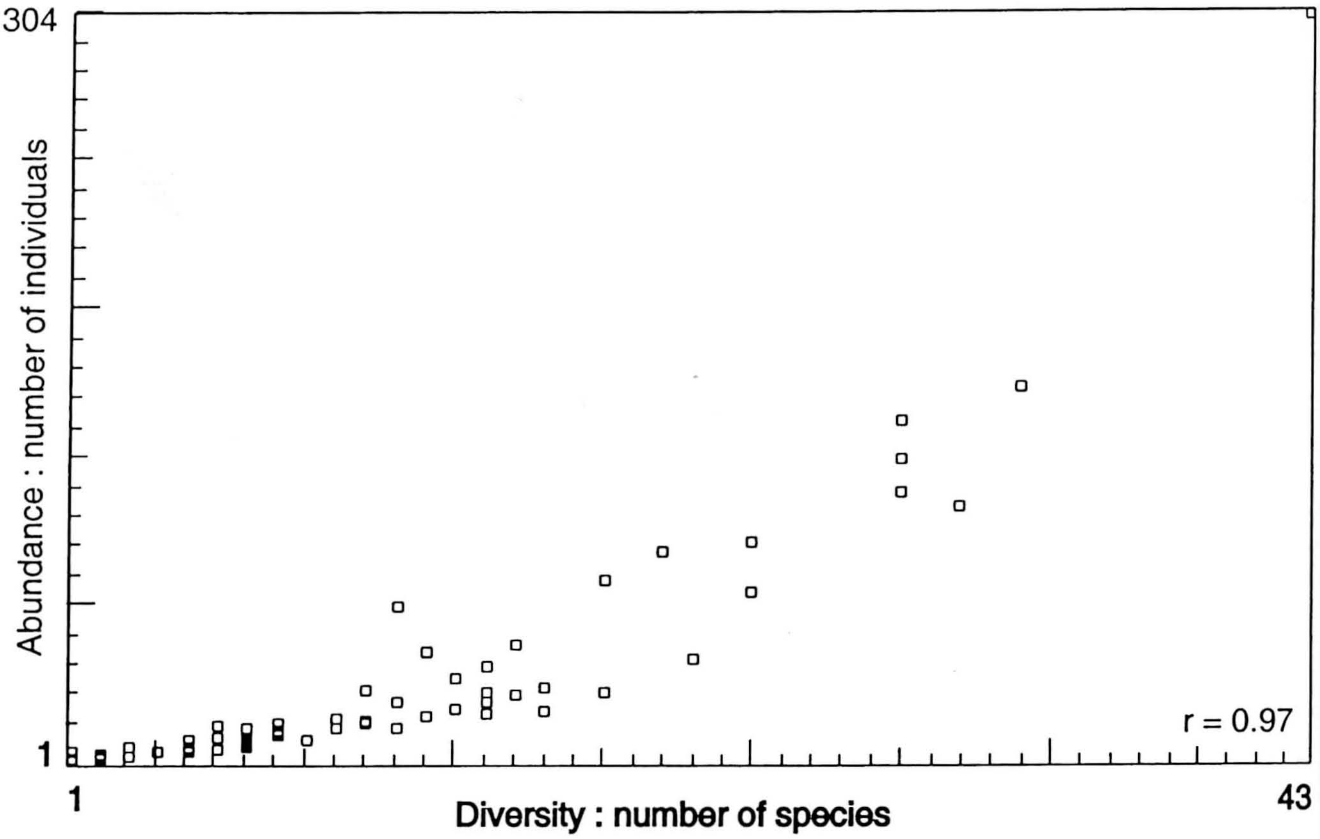
Bottom sediment samples were collected from 143 stations in Kagoshima Bay and three stations off the mouth of the bay from 1972 to 1978 by Oki (text-fig. 3). For most of them, we have pertinent ecological data such as geographic position, composition and grain size characteristics (Oki 1989, Tabl. 2). The sampling was performed by the RV "Keiten - maru" of the Faculty of Fisheries, Kagoshima University. For the method of sampling, refer to Oki (1989). All the samples were collected by using Phleger gravity corers. The top one centimeter of each sediment-core, amounting to approximately 10 cc of sediment, was sampled from each core. Collected sediment was washed through a 74 µm sieve and dried, and then picked for ostracods.

For the specification of successive assemblages from the Mouth to the Head of the bay, various biocoenotic indices and statistical methods were introduced.

Abundance - number of individuals per station (table 1 and text-figs. 5-6).

Number of taxa (here of species) - indicates species richness (diversity) per station and per area.

Comparison - the profile of relative frequencies of species in different parts of the Bay compared with the average profile, by means of euclidian distance (^{2}) (table 2)



TEXT-FIGURE 5
Abundance versus diversity of ostracods for the whole basin.

We examine here groups of species to see if they are typical of different areas of the bay. We group sampling sites according to their location in the bay (text-fig. 3). Tables 1 and 2 contain six main environments and 143 species. 59 species, documented by fewer than 5 individiduals, were not included. The remaining contingency table could be subjected to the classical χ^2 test to check the possibility of dependency between species and location in the bay. Unfortunately, total frequencies are too low (<5) and the test could not be performed. The best remaining possibility was to compare the profiles of the relative frequencies of species in every part of the bay with the average profile by means of an euclidian distance (^{2}). This is the sum of the squared differences between the relative frequencies of the species of the whole basin:

$$\rho^2 = \sum_{i=1}^{n} \left[\frac{\left(\frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} - \frac{\sum_{i=1}^{n} x_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{p} x_{ij}} \right)^2}{\frac{\sum_{i=1}^{n} x_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{p} x_{ij}}} \right]$$

where X_{ij} is the number of individuals of the species j in the sample i, and n the total number of individuals.

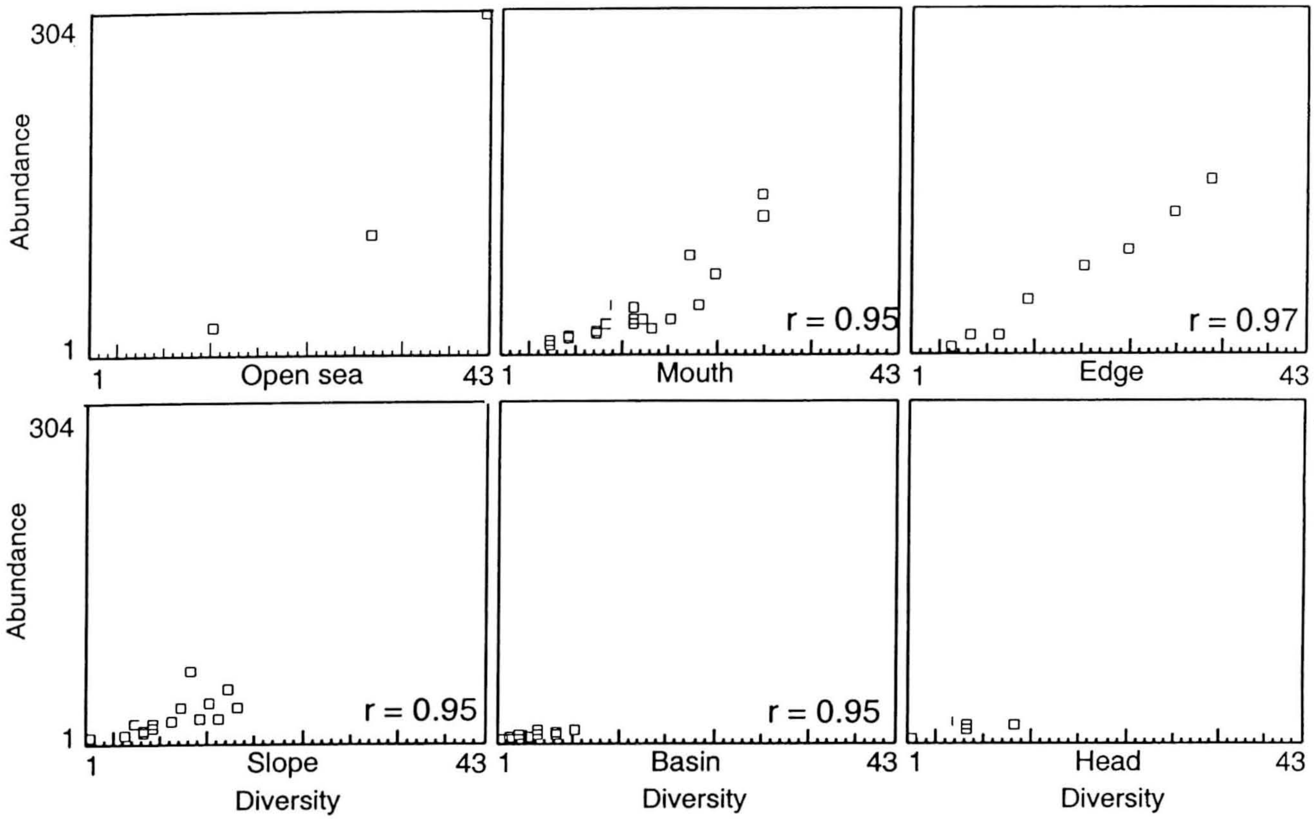
The contribution to ρ2 of one species is the ratio between one element of the sum

$$\left(\frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} - \frac{\sum_{i=1}^{n} x_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{p} x_{ij}} \right)^2$$

and the sum

$$\left(\frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} - \frac{\sum_{i=1}^{n} x_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{p} x_{ij}} \right)$$

is used to show whether the species is more abundant or less in any part of the basin that in the whole basin. Each environment can be associated with a group of species whose contributions to is greater than the mean. But these species are characteristic either because they are more abundant in this part of the bay than in the whole basin (positive contribution to ρ^2), or because they are less abundant or absent (negative contribution to ρ^2). We will only consider species whose contribution is greater than the mean contribution, 1.2% (100/84, 84 is the number of species kept in the initial table) (table 2 and text-fig. 7). Thus one species will be over-represented or under-represented in one environment, if its abundance is greater or lesser than the mean abundance of the whole samples for the whole bay.



TEXT-FIGURE 6
Abundance versus diversity of ostracods for different settings of the bay.

Correspondence analysis (CA) encompassing taxa and samples illustrates proximities between the profiles of species and populations (Benzécri 1973; Hill 1974; Diday et al. 1982; Greenacre 1984) which may be invoked to put forward the hypothesis that the composition of the ostracod faunas relates to environments (text-figs. 8 and 9). The results of CA have been improved by cluster analysis performed by using abscissa of different species and sites whose contribution to the mean is higher on the first three factors (text-fig. 10). The amalgamation strategy used in the present case is to minimize the intragroup variance.

RESULTS

Abundance and species richness (diversity)

Although ostracod specimens are very rare at every station (n=26 in average/station), we have tried to bring to light a relation between abundance and species richness. A total of 143 species of ostracods were found in the surface sediments of Kagoshima Bay (table 1). The most obvious characteristics of this fauna are that there are large variations in the number of individuals among different sites as well as different species. We found 304 individuals and 43 species at site 146 but only 1 individual at site 42. In the same way, 35 species are represented by only 1 specimen, 59 by less than 5.

The relationship between abundance and the number of species is astonishingly regular (text-fig. 5) and obviously nonlinear. The number of individuals increases faster than the number of species. The regression that gives the best fit is:

Abundance = 0.041 Species richness 2.35 (r=0.973).

Although this simple statistical relationship explains 95% of the total variance, it generalizes for the whole bay with six distinct environmental settings. If we plot, on the same scale, these variables for the separate bay areas (text-fig. 6), different kinds of relations are seen. First of all, the maximum number of species and maximum abundance are very high in the Open Sea and decrease steadily in the Basin and Bay Head areas. Moreover, the shape of the relationship is not the same everywhere. For the Open Sea, it is not possible to compute an equation due to the number of sites, but it is clearly non linear. For the Bay Mouth, the best fit is obtained for:

Abundance = 0.005 Species richness 2.95 (r = 0.95)

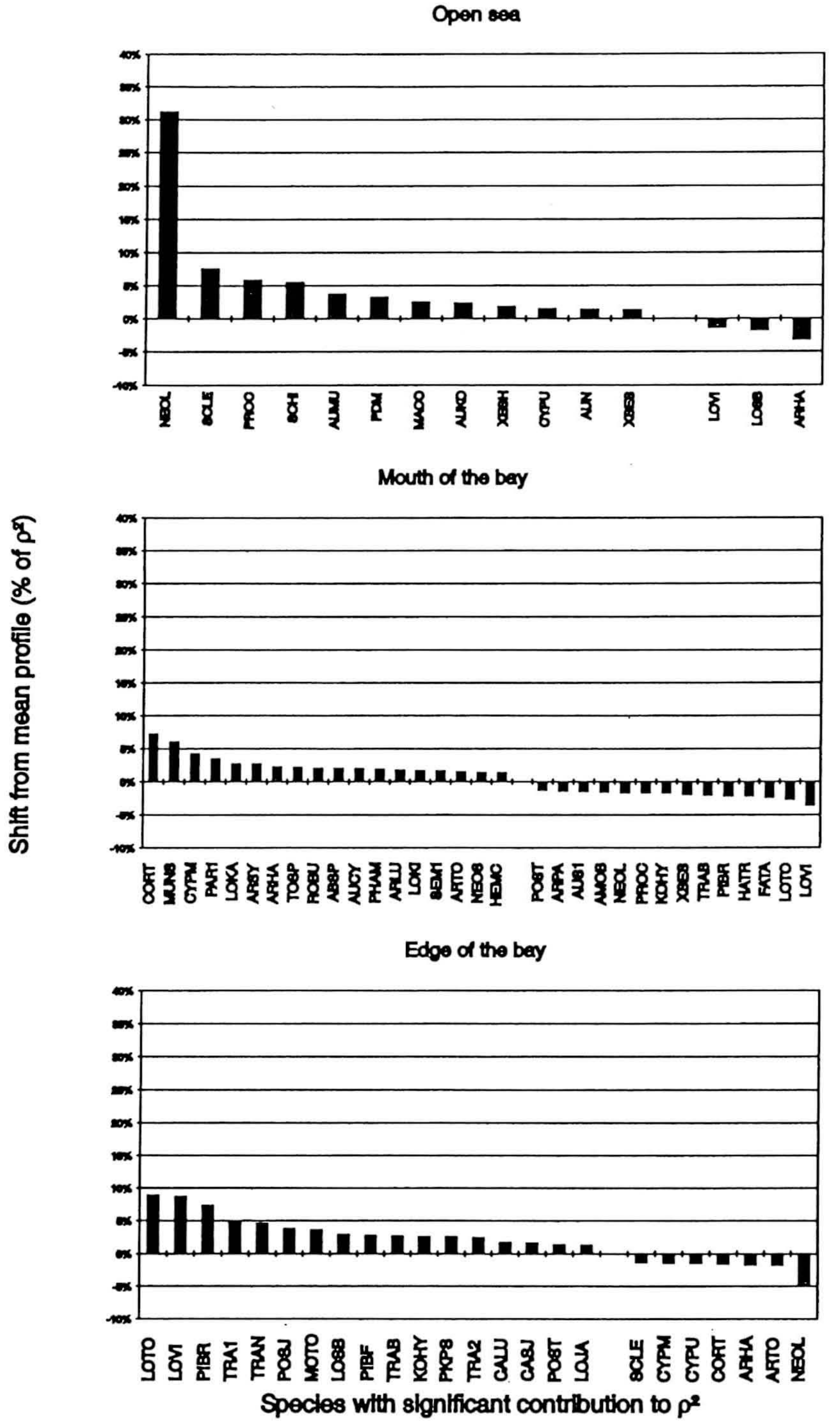
For the Margin, the Slope and the Basin, relations are linear (text-fig. 6):

Margin: Abundance = 3.93 Species richness (r= 0.97)

Slope: Abundance = 2.15 Species richness (r=0.95)

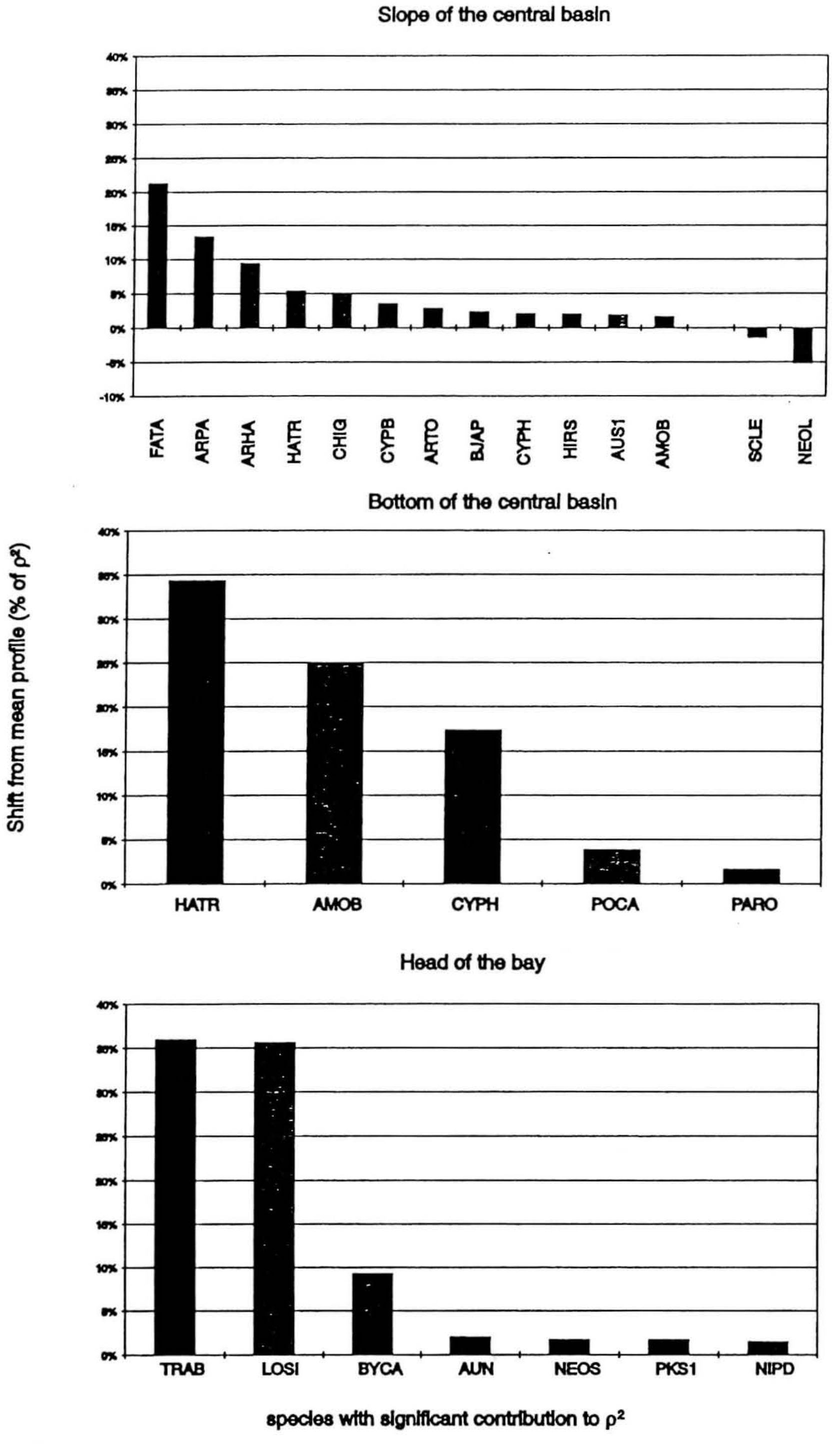
Basin: Abundance = 1.27 Species richness (r=0.95).

For the Bay Head, we do not have enough samples to compute the regression. Thus, in areas such as Open Sea and Bay Mouth, the frequency of individuals increases very quickly. In environments farthest from the Open Sea, this increase is not noticeable. The slope of the regression line decreases from the Margin to the Basin.



TEXT-FIGURE 7

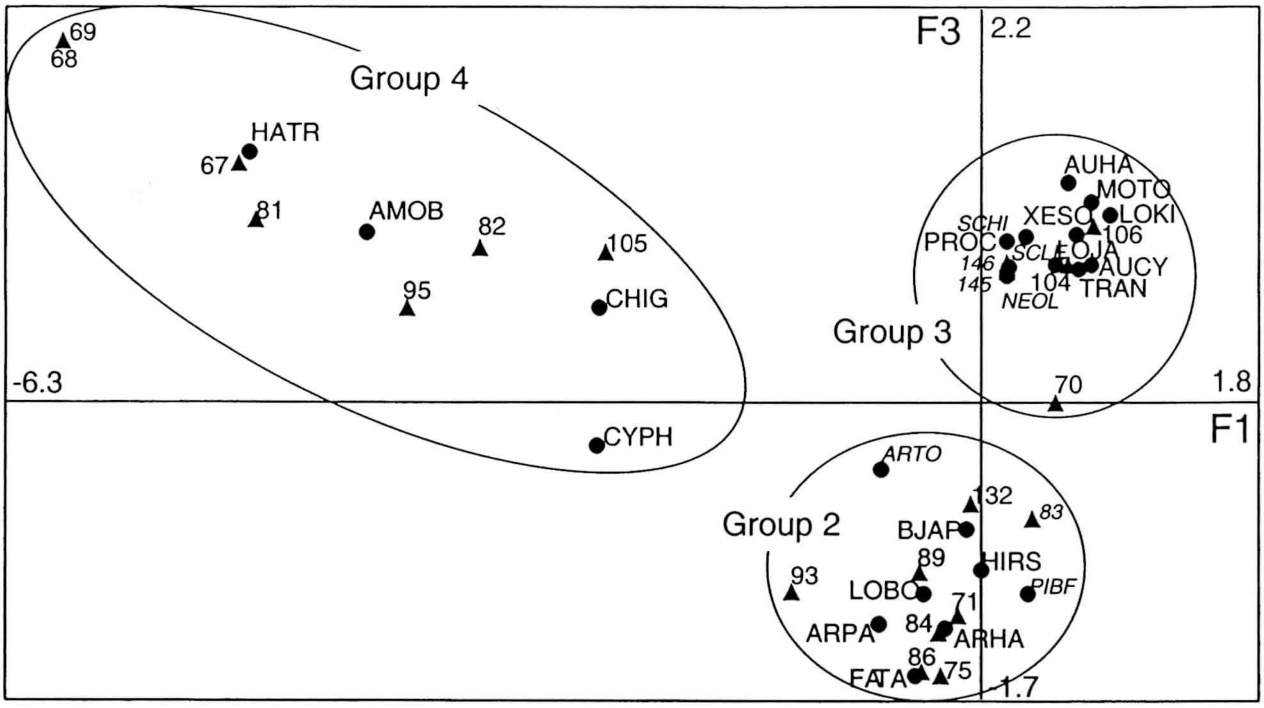
Contribution of the different species to the distance () between relative abundances at the sampling sites in different areas of the bay and the mean relative abundance in the whole bay. Abbreviations of the names of species: ABSP *Abrocythereis* sp., AMOB *Ambtonia obai*, ARHA *Argilloecia hanaii*, ARLU *A. lunata*, ARPA *A. parallela* ARSY *A. symmetrica*, ARTO *A. toyamaensis*, AUCY *Aurila cymba*, AUKO *A. okayamensis*, AUMU *A. munechikai*, AUN *A.* cf. *inabai*, AUS1 A. sp.1, BJAP *Bradleya japonica*, BYCA *Bythoceratina cassidoidea*, CALU *Callistocythere undulatifacialis*, CASJ *C. subjaponica*, CHIG *Chejudocythere higashikawai*, CORT *Cornucoquimba tosaensis*, CYPB *Cytheropteron subuchioi*, CYPH *C. hanaii*, CYPM *C. miurense*, CYPU *C. uchioi*, FATA *Falsobuntonia taiwanica*, HATR *Hanaiborchella triangularis*, HEMC *Hemicytherura cuneata*, HIRS *Hirsutocythere ? hanaii*, KOHY *Kobayashiina hyalinosa*, LOJA *Loxoconcha japonica*, LOKA *L. kattoi*, LOKI *L. kitanipponica*, LOSB *L.* sp.B, LOSI *L. sinensis*, LOTO *L. tosaensis*, LOVI *L. viva*, MACO *Macrocyprina okinawae*, MOTO *Moosella tomokoae*, MUNS *Munseyella* sp., NEOL *Neonesidea oligodentata*, NEOS *Neonesidea* sp., NIPD *Nipponocythere delicata*, PAR1 *Paracytherois* sp. 1, PARO *Paijenborchella iocosa*, PDM *Pseudocythere* cf *moneroni*, PHAM *Phlyctocythere hamanensis*, PIBF *Pistocythereis bradyformis*, PIBR *P. bradyi*, PKPS *Parakrithella pseudadonta*, PKS1 *Parakrithella* sp. 1, POCA *Pacambocythere humilitorus*, POSJ *Pontocythere subjaponica*, POST *P. subtriangularis*, PROC *Propontocypris crocata*, ROBU *Robustaurila* sp., SCHI *Schizocythere kishinouyei*, SCLE *Sclerochilus semirutrens*, SEM1 *Semicytherura* sp. 1, TOSP *Acanthocythereis* sp.1, TRA1 *Trachyleberis* sp. 1, TRA2 *Trachyleberis* sp.2, TRAB *T. scabrocuneata*, TRAN *T. niitsumai*, XESH *Xestoleberis hanaii*, XSES *X. sagamiensis*.



TEXT-FIGURE 7
Continued.

Concerning relative frequencies of species in different parts of the bay and their respective distributions (text-fig. 7), examination of table 2 shows that most species have environmental preferences, and some are wholly confined to a particular environment, according to our sampling.

Open sea: This environment is characterized by the over-representation of twelve species and the under-representation of three species (table 2). Usually, the former are found outside or at the mouth of the bay but always under oceanic influences. They do not characterize the inner parts of the bays but they can adapt to inner bay conditions (Ishizaki 1968a, 1981; Hanai, Ikeya, Sekiguchi and Yajima 1977; Ikeya and Suzuki 1991; Ikeya, Zhou and Sakamoto 1992; Yajima 1982). At a glance (table 2), it is obvious that *Schizocythere kishinouyei* (Kajiyama 1913) (SCHI), *Macrocyprina okinawae* Maddocks 1990



TEXT-FIGURE 8
Correspondence analysis (CA) of Table 1. Representation of samples in the space of the F1-F3 axes. (F1, F3). Black circles represent the species; triangles represent the sites. Sites and species in italics are those belonging to an other group. They seem to be associated to a group which is not their own, due to the projection of a multidimensionnal space on one plane.

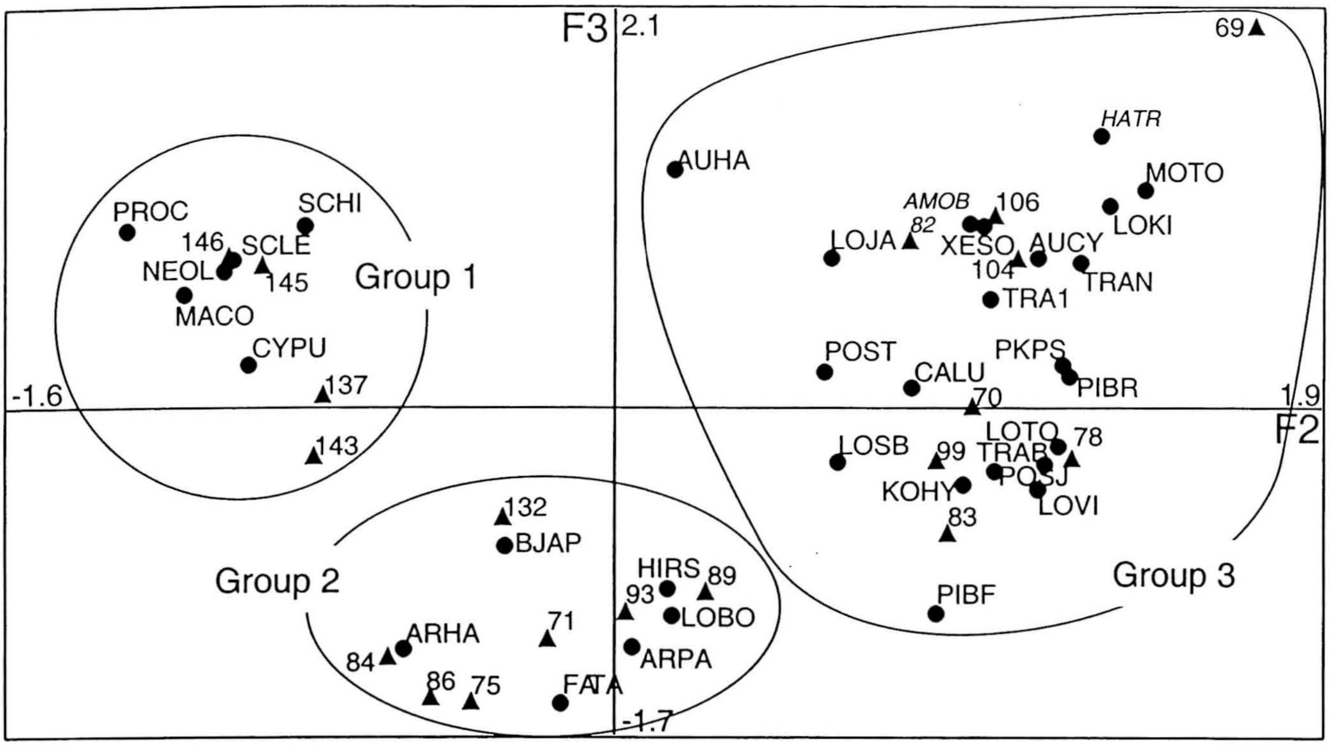
Abbreviations of the name of species: AMOB *Ambtonia obai*, ARHA *Argilloecia hanaii*, ARPA *A. parallela*, ARTO *A. toyamaensis*, AUCY *Aurila cymba*, AUHA *A. hataii*, BJAP *Bradleya japonica*, CHIG *Chejudocythere higashikawai*, CYPH *Cytheropteron hanaii*, FATA *Falsobuntonia taiwanica*, LOBO *Lobosocytheropteron donghaïensis*, HATR *Hanaiborchella triangularis*, HIRS *Hirsutocythere ? hanaii*, LOJA *Loxoconcha japonica*, LOKI *Loxoconcha kitanipponica*, LOSB *L.* sp. B, LOTO *L. tosaensis*, LOVI *L.viva*, MOTO *Moosella tomokoae*, NEOL *Neonesidea oligodentata*, PIBF *Pistocythereis bradyformis*, PROC *Propontocypris crocata*, SCHI *Schizocythere kishinouyei*, SCLE *Sclerochilus semirutrens*, TRAN *Trachyleberis niitsumai*, XESO *Xestoleberis opalescenta*.

(MACO), *Aurila okayamensis* Okubo 1988 (AUKO), *Xestoleberis hanaii* Ishizaki 1968 (XESH) are representative of this environment. The first three species occur only in the Open sea environment; *X. hanaii* (XESH) occurs in lower abundance in every other environment of the Bay (table 3). Among the under-representing species, *Loxoconcha viva* Ishizaki 1968 (LOVI) has not been found in this environment but *Argilloecia hanaii* Ishizaki 1981 (ARHA) occurs in station 144 and *Loxoconcha* sp. B(LOSB) in station 146 (table 3). It is worthy of note that *Neonesidea oligodentata* (Kajiyama 1913) (NEOL), *S. kishinouyei* (SCHI), *Xestoleberis sagamiensis* Kajiyama 1913 (XSES) and *M. okinawae* (MACO) occur in station 34 (Head of the bay).

Bay Mouth: Eighteen species are over-represented and fourteen are under-represented (table 2). Of the former, thirteen species are exclusively representative of the Mouth environment and *Munseyella* sp. (MUNS.), Paracytherois sp. 1 (PAR1) and Acanthocythereis sp. 1 (TOSP) occur only in this environment (table 3). The others have been found in several environments of Kagoshima Bay (one or two specimens): the Mouth environment includes shallow stations along the Osumi and the Satsuma Peninsulas and deeper ones in its Central part. Usually, these species are found under the influence of the Open sea. Some of them can occur in bathyal environments and others are known in coastal environments as shallow species (Ishizaki 1968a; Ishizaki 1971; Ishizaki and Irizuki 1990; Ikeya and Hanai 1982; Ikeya and Suzuki 1992; Ikeya and Cronin 1993).

Among the under-represented species, *Propontocypris crocata* Maddocks 1969 (PROC), *Aurila* sp. 1 (AUS1), *Ambtonia obai* (Ishizaki 1971) (AMOB) and *Kobayashiina hyalinosa* Hanai 1957 (KOHY) have not been found in the Mouth environment.

Margin: Seventeen species are over-represented and seven are under-represented. Of the former, ten species are characteristic of this environment and four of them -*K. hyalinosa* (KOHY), *Moosella tomokoae* (Ishizaki 1968) (MOTO), *Pistocythereis bradyformis* (Ishizaki 1968) (PIBF), *Callistocythere subjaponica* Hanai 1957 (CASJ) - occur only in this environment (table 2). On the whole, these species which are characteristic of this environment are usually found either outside or inside the bays; some of them can live down to 250m deep, but are occasional beyond 50m (Ishizaki 1968, 1969, 1971; Ikeya and Itoh 1991; Ikeya and Suzuki 1992; Ikeya and Cronin 1993); they are shallow-water species, even epiphitic. Most of them indicate the influence of the Open sea although *Parakrithella pseudadonta* (Hanai 1959) (PKPS) would not occur under the open sea flux (Ishizaki 1968a, 1971). Some of the species which are representative here characterize the mud bottom, with a high density of pellets; such species as *Trachyleberis scabrocuneata* (Brady 1880) (TRAB) and *Callistocythere undulatifacialis* Hanai 1957 (CALU) occur mainly in polluted areas as a consequence of human waste (Yajima 1992; Ikeya and Itoh 1991). It is worth noting that *Loxoconcha viva* shows the same distribution as *Buliminella elegantissima* (D'Orbigny) (Oki 1989, Fig. 46). This foraminifer is typically a polluted species. No species rep-



TEXT-FIGURE 9
Correspondence analysis (CA) of table 1. Representation of samples in the space of the F2-F3 axes (F2, F3). Black circles represent the species; triangles represent the sites. Sites and species in italics are those belonging to an other group. They seem to be associated to a group which is not their own, due to the projection of a multidimensionnal space on one plane.

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resentative of this environment is characteristic of the basin environment (table 2). *T. scabrocuneata* is also characteristic of the Head environment.

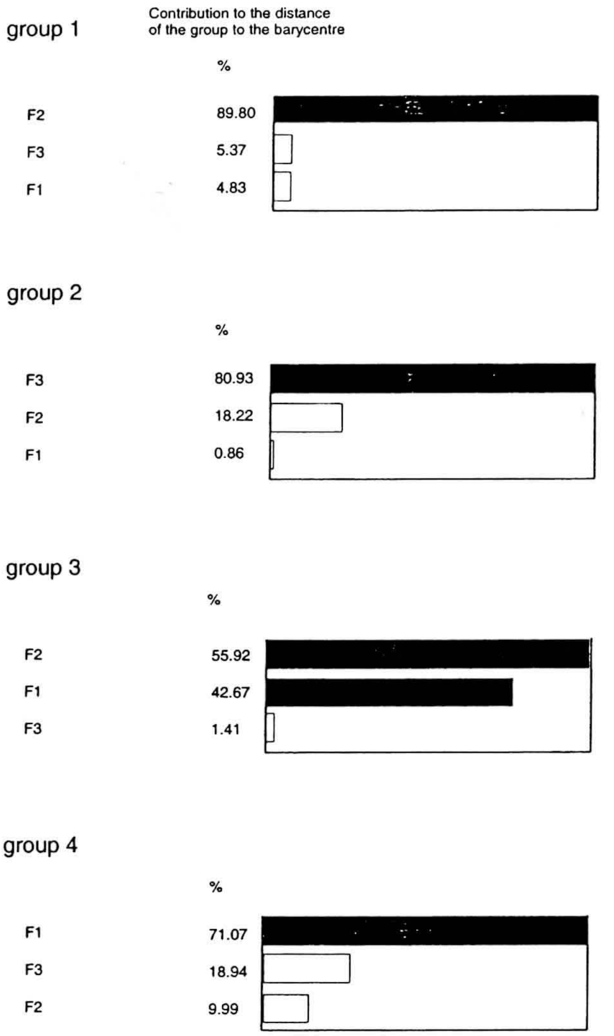
Slope: Twelve species are over-represented and two are under-represented. The latter do not occur in any stations of the Slope environment. The former have been found in the other environments of the bay, except in the Head environment (table 3). Among them, *Chejudocythere higashikawai* (CHIG), *Cytheropteron subuchioi* Zhao 1988 (CYPB), *Bradleya japonica* Benson 1972 (BJAP), *C. hanaii* (CYPH) and *Hirsutocythere? hanaii* (HIRS) significantly represent only this environment. As a whole, characteristic species of this environment inhabit internal Japanese bays: such species as *Bradleya japonica* (BJAP) and *A. hanaï* Ishizaki 1981 (ARHA) can occur in the open sea (Ishizaki 1971, 1981; Ikeya and Cronin 1993; Ikeya and Suzuki 1992). Among them, *Falsobuntonia taiwanica* Malz 1982 (FATA), *C. higashikawai* (CHIG), *B. japonica* (BJAP), *A. obai* (AMOB) are reported from a substrate rich in organic matter. According to Ikeya and Itoh (1991), *A. obai* could live in environments unfavorable to ostracods: it has been found in the deepest stations of the Slope environment and in the Basin environment. Most of these species are found at a depth of 200m, but sometimes, they can occur in deeper environments e.g. *A. toyamaensis* (ARTO) and *F. taiwanica* (FATA) (Ishizaki and Irizuki 1990; Ikeya and Suzuki 1992).

Basin: The species that are characteristic of this environment are neither under-represented nor characteristic of the Open sea environment (table 2). None of them has ever been found in the Open-sea and Bay Head environments (table 3). They are usually found on a fine substrate and mostly beyond a depth of 100m. *Pacambocythere humilitorus* Malz 1982 (POCA) and *Paijenborchella iocosa* Kingma 1948 (PARO) are also representative of this environment only (Ishizaki 1981; Ikeya and Itoh 1991).

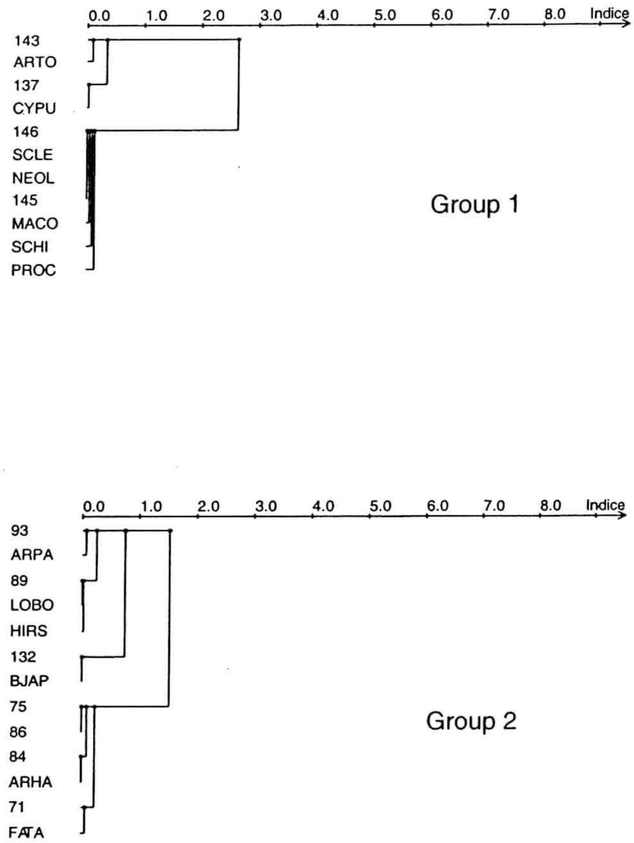
Bay Head: Seven species are over-represented. They can occur in the other environments (table 3), except the Basin environment. Four of them are characterisitic of the Bay Head environment only. Curiously, *Aurila* cf. *inabai* Okubo 1976 (AUN) is also representative of the Open sea environment, *Neonesidea* sp. (NEOS) of the Mouth environment and *Trachyleberis scabrocuneata* (TRAB) of the Margin environment.

Relative representation in different environments. Some species tolerate large variations of environmental parameters, occuring in several environments of the bay. Environmental conditions can be different among stations of the same environment. Some species cover several environments.

Species over-representing in the Open-sea environment wanes into under-representation toward the Bay Mouth, Margin and Slope environments, and inversely, except for *A. hanaii* and *L.*



TEXT-FIGURE 10
Cluster analysis performed by using abscisses of different species and sites of which contribution is higher than the mean on the first three axes. Abbreviations of the names of species: see text-figures 8 and 9.



TEXT-FIGURE 10
Continued.

viva. The former is under-represented in the Margin environment and the latter in the Mouth environment. We can suggest the hypothesis that *A. hanaii* would occur rather in the deepest part of the inner bay. On the other hand, *L. viva* occur at sites 63 (Head environment), 100 (Slope environment), 106, 113 and 116 (Mouth environment), inhabiting the littoral environment.

Species over-represented in the Bay Mouth environment are under-represented in the Margin environment, and inversely, *Argilloecia hanaii* and *A. toyamaensis* are also over-represented in the Slope environment.

No species over-represented in the Margin environment is over-represented in the Slope environment. *Ambtonia obai, Hanaiborchella triangularis* (Hanai 1970) and *Cytheropteron uchioi* Hanai 1957 are over-represented in the Slope and Basin environments which are the deepest and most depleted of oxygen. It is worth noting that the first mentioned species does not occur in the Margin, Bay Mouth, Bay Head or Open sea environments and the second one in the Open sea or Bay Head environments, and the third one in the Open sea, Margin and Head environments (table 1). *A. obai* can occur where the density of ostracods is very low. The chemical composition of ambient water rather than bathymetry would be a limiting factor.

No species that is over- or under-represented in the Margin environment is over- or under-represented in the Basin environment and no species that is over-represented in the Basin environment is over-represented in the Head environment.

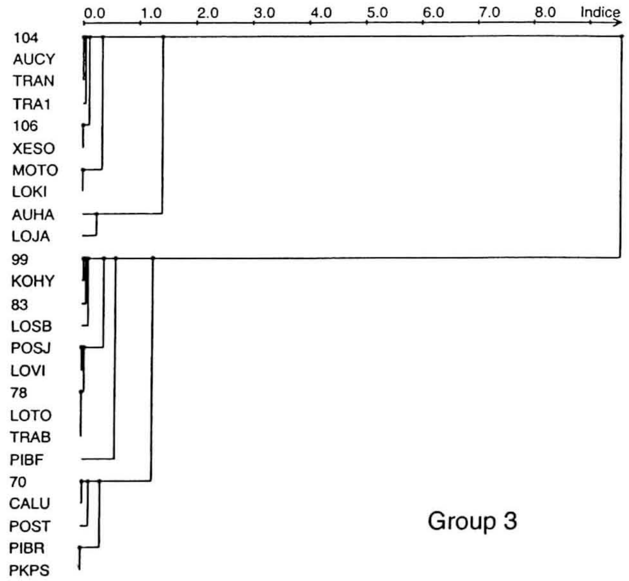
Correspondence analysis (CA) and cluster analysis

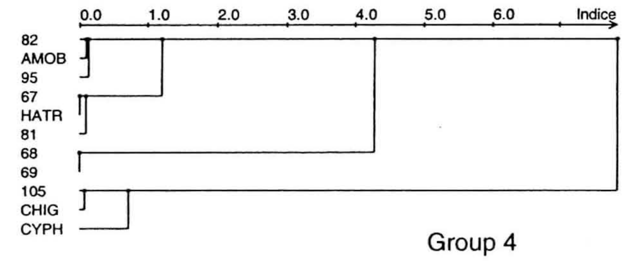
We subjected the data in Table 1 to CA and cluster analysis (text-figs. 8-10). The first three axes define environmentally significant species groups. They represent respectively 9.1, 8.3 and 7% of the total inertia.

Sites 67, 68, 69, 81, 82, 93, 95 and 105 contribute to F1 (relative contribution = 0.768). They are located in the Central part of the Bay; they belong to the Slope and the Basin under the influence of the water mass d (Oki 1989, Fig. 34 and Tabl. 8 and 10). Hot-springs occur at sites 67, 68, 69 and 105 and volcanic ashes are reported at sites 81, 82 and 95. Associated species are *Hanaiborchella triangularis, Ambtonia obai,* which are reported from low density ostracod biofacies (Ikeya and Itoh 1991) as well as *Cytheropteron hanaii* and *Chejudocythere higashikawai,* which occur on fine bottom sediments with abundant organic matter (Ikeya and Suzuki 1992). In Kagoshima Bay, the first two species have been found only in the Slope and Basin environments at stations under the influence of the stagnant water mass b or d. The latter two can occur in other environments at shallower stations, even under the influence of the water mass a or c. They could adapt to depleted oxygen conditions. Sites and species which contribute together to Axis 1 constitute group 1 of cluster analysis. First axis characterizes deep and stagnant water environments of Kagoshima Bay.

Sites 104, 70, 106, 78, 99 and 83 contribute to F2 (relative contribution=0.377) and are located along the margin of the bay, in the Bay Margin or the Bay Mouth environment. All, except site 99, are under the influence of the water mass c. Site 99 is under the influence of the water mass a, but is located in front of the outlet of a small river. Associated species are *Callistocythere undulatifacialis, Xestoleberis opalescenta* Shornikov 1974, *Aurila cymba* (Brady 1869), *Loxoconcha japonica* Ishizaki 1968, *L. tosaensis* Ishizaki 1968, *L. kitanipponica* Ishizaki 1971, *L. viva, Moosella tomokoae, Loxoconcha* sp. B, *Pistocythereis bradyi, Parakrithella pseudadonta, Pontocythere japonica* (Hanai 1959), *Pontocythere subtriangularis, T. scabrocuneata* and *Kobayashiina hyalinosa*. All of them are reported in Japanese inner bays. They are usually found in water less than 150m deep and some of them are epiphytic. They could tolerate slightly lowered salinities (Ikeya and Suzuki 1992; Shornikov 1974). Nevertheless, they also occur at deeper stations as in Kagoshima Bay in the Mouth, Open Sea and Basin environments. Some specimens have been found in stations under the influence of the water masses a, b or d. However, they occur largely at stations under the influence of the water mass c. Some species, such as *P. pseudadonta,* are never reported at places under the influence of open-sea water flow. They occur on a sandy to muddy bottom with abundant organic matter. Some of them, such as *T. scabrocuneata,* are abundant near the human waste (Yajima 1992). On the opposite side, sites 146 and 145 in the Open sea environment and sites 137 and 143 in the Mouth environment also contribute to Axis 2. The first three are under the influence of the water mass a, the fourth is located at the boundary between the water masses a and b. Associated species are *Schizocythere kishinouyei, Argilloecia toyamaensis* Ishizaki and Iruzuki, 1990, *Neonesidea oligodentata, Sclerochilus semirutrens* Shornikov 1981, *Propontocypris crocata, Macrocyprina okinawae* and *Cytheropteron uchioi*. They are usually reported in the Open-sea environment, at the mouth of Japanese bays or even in the bathyal environment and some of them at shallower waters (Shornikov 1974; Bodergat and Ikeya 1988; Ikeya and Itoh 1990; Ikeya and Suzuki 1992; Bodergat et al.1997). In Kagoshima Bay, except *Macrocyprina okinawae,* they can adapt to inner bay conditions: *Sclerochilus semirutrens* and *Schizocythere kishinouyei* are found in the Margin environment, *Propontocypris crocata* and *Cytheropteron uchioi* in the Slope environment, *Argilloecia toyamaensis* in the Slope, Margin and Basin environments and *Neonesidea oligodentata* in the Margin and Basin environments. Two sets are opposite on the second axis; the first one groups sites and species in the Open sea environment, the second one, sites in the littoral and inner bay species, usually reported on the bottom with abundant organic matter. These two sets correspond to groups 2 and 4 in the hierarchical classification (text-fig. 10).

Site 106 which is under the influence of the water mass c contributes to F3. Associated species are *Aurila hataii* and *L. japonica,* both of which are reported in Japanese inner bays. They live in water shallower than 100 meters deep. This set constitutes a subgroup of group 2 of the hierarchical classification (text-fig. 10). On the opposite side, sites 71, 75, 84, 86, 89, 93 and 132 also contribute to Axis 3. All, except the last one, are located either on the Slope or at the boundary between the Margin and the Slope. Site 86 is located at the top of a mount in the Centre of the Bay. From a bathymetric point of view, it is equivalent to sites on the Slope (text-fig. 3). According to Oki (1989, Fig. 34 and Tables 8 and 10), these sites are located either at the boundary between the water masses b and c (71, 85, 89), or a and b (132) or under the influence of the water mass d (84, 86, 93). Associated species are *Argilloecia hanaii, A. parallela* Zhao 1982, *B. japonica, Hirsutocythere* ? *hanaii* Ishizaki 1981, *F. taiwanica* and *Lobosocytheropteron donghaisensis* (Zhao 1988); all of which are reported in Japanese inner bays and also on platforms (Ishizaki 1981; Ikeya et al. 1992). In Kagoshima Bay, the first two occur in the Open sea, Bay Mouth, Slope, Basin and Margin environments, the fourth in the Open sea, Mouth, Slope and Margin environments, the third and the fifth in the Mouth, Slope and Margin environments and the last one in the Mouth, Slope, Basin and Margin environments. They can live in deep and shallow places and can colonize at the inner parts of the bay from the Open sea environment, in particular at places under the influence of more or less stagnant water masses. This set is equivalent to group 3 in the hierarchical classification.





TEXT-FIGURE 10
Continued.

DISCUSSION

In Kagoshima Bay, ostracod faunas are mainly represented by warm-water species. This indicates the influence of the

TABLE 1
Identified species of ostracods.

Species	
Abrocythereis ryukyuensis	ABYU
Abrocythereis sp.	ABSP
Acanthocythereis sp. 1	TOSP
Actinocythereis kisarazuensis	ACTK
Actinocythereis sp.	ACSP
Ambtonia obai	AMOB
Argilloecia cf. parallela	ARPA
Argilloecia hanali	ARHA
Argilloecia lunata	ARLU
Argilloecia symmetrica***	ARSY
Argilloecia toyamaensis	ARTO
Aurila cf inabai	AUN
Aurila corniculata	AUCO
Aurila cymba	AUCY
Aurila hataii	AUHA
Aurila inabai	AUNA
Aurila kiritsubo	AUKI
Aurila munechikai	AUMU
Aurila okayamensis	AUKO
Aurila sp. 2	AUP2
Aurila sp.1	AUS1
Aurila uranouchiensis	AURA
Bassleriites longiuscula	BALO
Bicornucythere bisanensis	BIBI
Bradleya japonica	BJAP
Bythoceratina cassidoidea	BYCA
Bythoceratina cf. hanaii	BYHA
Bythocypris affinis affinis	BYTA
Bythocyterina pacifica	BYPA
Callistocythere asiatica	CALA
Callistocythere cf. undulatifacialis	CAL
Callistocythere japonica	CAJA
Callistocythere subjaponica	CASJ
Callistocythere undulatifacialis	CALU
Cardobairdia sp.	CRSP
Chejudocythere higashikawai	CHIG
Cletocythereis bradyi	CLEB
Coquimba ishizakii	COIS
Coquimba subgibba	COSU
Coquimba cf. equa	COR
Cornucoquimba tosaensis	CORT
Cypridopsis ? sp.	CYPS
Cyprinotus sp.	CYPR
Cythere nishinipponica	CYNI
Cytherelloidea sabahensis	CYLS
Cytherelloidea sp.	CYLP
Cytherois decorata	CYRD
Cytherois sp.	CYRS
Cytheropteron hanaii	CYPH
Cytheropteron miurense	CYPM
Cytheropteron sp. 1	CYP1
Cytheropteron subuchioi	CYPB
Cytheropteron uchioi	CYPU
Eucythere cf. serrata	EUCS
Eucytherura neoalae	EUCN
Falsobuntonia taiwanica	FATA
Hanaiborchella hanaii	HAHA
Hanaiborchella triangularis	HATR
Hemicytherura cuneata	HEMC
Hemicytherura tricarinata	HEMT
Hirsutocythere ? hanaii	HIRS
Kangarina sp.	KASP
Kobayashiina hyalinosa	KOHY
Kobayashiina sp.	KOSP
Krithe cf. japonica	KRJA
Leptocythere sp.	LESP
Lobosocytheropteron donghaisensis	LOBO
Loxoconcha cf. viva	LOV
Loxoconcha epeterseni	LOXE
Loxoconcha japonica	LOJA
Loxoconcha kattoi	LOKA
Loxoconcha kitanipponica	LOKI
Loxoconcha optima	LOPT
Loxoconcha sinensis	LOSI
Loxoconcha sp. 1	LOS1
Loxoconcha sp. 2	LOS2
Loxoconcha sp.3	LOS3
Loxoconcha sp.B	LOSB
Loxoconcha tosaensis	LOTO
Loxoconcha tosamodesta	LOMO
Loxoconcha viva	LOVI
Loxocorniculum mutsuensis	LOXM
Macrocyprina okinawae	MACO
Microcythere sp. 1	MIC1
Microcythere sp. 2	MIC2
Moosella tomokoae	MOTO
Munseyella cf. reticulosa	MUNR
Munseyella sp.	MUNS
Neonesidea oligodentata	NEOL
Neonesidea sp.	NEOS
Nipponocythere delicata	NIPD
Nipponocythere inornata	NIPI
Paijenborchella iocosa	PARO
Paracytheridea minaminipponica	PAMI
Paracytherois cf extensa	PARE
Paracytherois sp. 1	PAR1
Paradoxostoma sp.	PARS
Parakrithella pseudadonta	PKPS
Parakrithella sp. 1	PKS1
Perissocytheridea bosoensis	PEBO
Perissocytheridea retiformis	PERT
Perissocytheridea tschoppi	PATS
Phlyctocythere hamanensis	PHAM
Pistocythereis bradyformis	PIBF
Pistocythereis bradyi	PIBR
Platymicrocythere sp.	PLAT
Pacambocythere humilitorus	POCA
Polycope cf dispar	POLD
Polycope sp.	POLS
Pontocythere cf. miurensis	POM
Pontocythere japonica	POJA
Pontocythere sekiguchii	POSE
Pontocythere subjaponica	POSJ
Pontocythere subtriangularis	POST
Propontocypris cf. paradispar	PRO
Propontocypris crocata	PROC
Propontocypris japonica	PROJ
Pseudocythere cf moneroni	PDM
Pseudocythere frydli	PDFR
Pumilocytheridea sp.	PUM
Robustaurila salebrosa	ROSA
Robustaurila sp.	ROBU
Saida herrigi	SAID
Schizocythere kishinouyei	SCHI
Sclerochilus semirutrens	SCLE
Semicytherura cf elongata	SEM
Semicytherura elongata	SEME
Semicytherura henryhowei	SEMH
Semicytherura miurensis	SEMI
Semicytherura sestroretiformis	SEMS
Semicytherura sp. 1	SEM1
Semicytherura sp. 2	SEM2
Trachyleberis niitsumai	TRAN
Trachyleberis scabrocuneata	TRAB
Trachyleberis sp. 1	TRA1
Trachyleberis sp. 2	TRA2
Trachyleberis sp. 4	TRA4
Xestoleberis hanaii	XESH
Xestoleberis ishizakii	XESI
Xestoleberis opalescenta	XESO
Xestoleberis sagamiensis	XSES
Xestoleberis sp. B	XESB
Xiphichilus sinensis	XIPH
Yajimaina nipponica	YAJI

Kuroshio Current. At stations located near the Mouth of the Bay, indices of abundance and diversity are high. The numbers of species and individuals decrease from the Mouth of the Bay towards the Basin and Head areas. In the latter, most of the stations are sterile.

The bay is subdivided into six topographic environments. They show the following features: 1) the topography is irregular, 2) the sampling stations are more or less deep and more or less distant from the seashore, 3) the substrate is composed of rather ill-sorted sediments as a consequence of the occurrence of strong currents inside the Bay, 4) evidence of volcanic activity is shown at some stations either by volcanic ashes in the sediments (stations 93, 87 and 82 in the Slope environment, 95, 81 and 76 in the Basin environment), or by fumaroles and hot springs (station 104 in the Margin environment, stations 105 and 98 in the Slope environment, stations 69, 68 and 67 in the Basin environment and most of the stations in the Head environment). Therefore, concerning the environmental conditions, each of the six environments is heterogeneous and seems to be made up of mosaics of biotopes.

Each environment is characterized by an over or under-representation of several species. The latter can have different ecological requirements. Shallow species as well as deeper ones characterize the Mouth environment where the topography is irregular. In return, over-represented ones in the Open-sea environment are under-represented in the Bay Mouth environment, the over-represented ones in the latter are under-represented in the Margin environment although these environments lie side by side. No over-represented species in the Margin environment characterize the Slope environment although the Margin and Slope environments, differing in water masses and bathymetry, adjoin. On the opposite side, *Ambtonia obai*, *Hanaiborchella triangularis* and *Cytheropteron hanaii* are over-represented in the Slope and Basin environments, having much the same bathymetry and water chemistry. It is worth noting that three over-represented species in the Bay Head environment, i.e.

TABLE 2
Contribution of the species to χ^2 between the different areas and the average for the whole bay. Abbreviations of the names of species: see Table 1.

Open sea	
NEOL	31,2%
SCLE	7,5%
PROC	5,9%
SCHI	5,5%
AUMU	3,7%
PDM	3,2%
MACO	2,4%
AUKO	2,3%
XESH	2,3%
CYPU	1,5%
AUN	1,3%
XSES	1,3%
LOVI	-1,3%
LOSB	-1,8%
ARHA	-3,2%

Mouth	
CORT	7,2%
MUNS	6,0%
CYPM	4,2%
PAR1	3,4%
LOKA	2,7%
ARSY	2,7%
ARHA	2,2%
TOSP	2,1%
ROBU	2,0%
ABSP	1,9%
AUCY	1,9%
PHAM	1,9%
ARLU	1,7%
LOKI	1,6%
SEM1	1,6%
ARTO	1,4%
NEOS	1,3%
HEMC	1,3%
POST	-1,3%
ARPA	-1,4%
AUS1	-1,5%
AMOB	-1,6%
NEOL	-1,7%
PROC	-1,7%
KOHY	-1,7%
XSES	-2,0%
TRAB	-2,1%
PIBR	-2,2%
LOTO	-2,2%
FATA	-2,4%
HATR	-2,7%
LOVI	-3,6%

Margin	
LOTO	8,9%
LOVI	8,7%
PIBR	7,3%
TRA1	4,9%
TRAN	4,6%
POSJ	3,8%
MOTO	3,6%
LOSB	3,0%
PIBF	2,8%
TRAB	2,7%
KOHY	2,6%
PKPS	2,6%
TRA2	2,4%
CALU	1,7%
CASJ	1,6%
POST	1,3%
LOJA	1,3%
SCLE	-1,3%
CYPM	-1,4%
CYPU	-1,4%
CORT	-1,5%
ARHA	-1,7%
ARTO	-1,7%
NEOL	-4,7%

Slope	
FATA	21,3%
ARPA	13,4%
ARHA	9,4%
HATR	5,3%
CHIG	5,1%
CYPB	3,5%
ARTO	2,8%
BJAP	2,3%
CYPH	2,0%
HIRS	2,0%
AUS1	1,8%
AMOB	1,6%
SCLE	-1,4%
NEOL	-5,1%

Basin	
HATR	34,3%
AMOB	24,8%
CYPH	17,4%
POCA	3,8%
PARO	1,6%

Head	
TRAB	36,0%
LOSI	35,6%
BYCA	9,2%
AUN	2,0%
NEOS	1,7%
PKS1	1,7%
NIPD	1,4%

Aurila cf. *inabai* (AUN), *Neonesidea* sp. (NEOS) and *Trachyleberis scabrocuneata* (TRAB), are also over-represented in the Open-sea, Bay Mouth and Edge environments, respectively. A branch of the Kuroshio Current enters through the Sakurajima Passage into the Bay Head environment, which is mainly occupied by acidic water mass e, resulting from the volcanic activity of Sakurajima.

Volcanism as well as water mass circulation could influence the distribution of ostracod populations. *Hanaiborchella triangularis*, *Ambtonia obai*, *Cytheropteron hanaii* and *Chejudocythere higashikawai* are associated with stations 67, 68, 69, 81, 82, 93, 95 and 105 where volcanic activity is indicated. All these stations are located in the Basin and Slope environments and are under the influence of the stagnant water mass d.

Station 104 (disposed to hot springs) is located in the Margin environment, as are stations 70, 106, 78, 83 and 99, where no volcanic activity is reported. All of them, except the last-mentioned, are under the influence of the polluted water mass c. Station 99 is in front of the mouth of a small river. Associated species are reported in the littoral environment and tolerate desalination of the environmental water, and most of the time occur on the substrates where pellets are abundant as a consequence of anthropic pollution.

Volcanic ashes have been found in sediments at stations 76 and 93. The former is located in the Basin environment and the second in the Slope environment. Like stations 71, 75, 84 (lowest part of the Margin environment), 86, 89 (Slope environment) and 132 (Mouth environment), stations 76 and 93 are associated with species reported from Japanese inner bay and/or platform environments. The stations range in depth from 88 to 222m. All these stations are located at the boundary area between either water masses a and b, or b and c, or under the influence of the water mass d: these water masses are more or less stagnant, although they move laterally over the year.

TABLE 3
Distribution of the over and under-represented species in the six environments of Kagoshima Bay.

species		Open sea	Mouth	Margin	Slope	Basin	Head
ABSP	Abrocythereis sp.		+	+	+	+	
AMOB	Ambtonia obai				+	+	
ARHA	Argilloecia hanaii	+	+	+	+	+	
ARLU	Argilloecia lunata	+	+	+	+	+	+
ARPA	Argilloecia cf. parallela		+	+	+		
ARSY	Argilloecia symmetrica		+	+	+		
ARTO	Argilloecia toyamaensis	+	+	+	+	+	
AUCY	Aurila cymba		+	+	+		
AUKO	Aurila okayamensis	+					
AUMU	Aurila munechikai	+					
AUN	Aurila cf inabai	+	+				+
AUS1	Aurila sp.1			+	+		
BJAP	Bradleya japonica	+	+	+	+	+	
BYCA	Bythoceratina cassidoidea	+	+				+
CALU	Callistocythere undulatifacialis	+	+	+	+		
CASJ	Callistocythere subjaponica			+			
CHIG	Chejudocythere higashikawai				+	+	
CORT	Cornucoquimba tosaensis	+	+		+	+	+
CYPB	Cytheropteron subuchioi	+	+		+		
CYPH	Cytheropteron hanaii		+		+	+	
CYPM	Cytheropteron miurense	+	+	+	+		+
CYPU	Cytheropteron uchioi	+	+		+		
FATA	Falsobuntonia taiwanica		+	+	+		
HATR	Hanaiborchella triangularis		+	+	+	+	
HEMC	Hemicytherura cuneata	+	+	+			
HIRS	Hirsutocythere ? hanaii	+	+	+	+		
KOHY	Kobayashiina hyalinosa			+			
LOJA	Loxoconcha japonica	+	+	+			+
LOKA	Loxoconcha kattoi	+	+				
LOKI	Loxoconcha kitanipponica		+	+			
LOSB	Loxoconcha sp.B	+	+	+	+		+
LOSI	Loxoconcha sinensis	+	+		+		+
LOTO	Loxoconcha tosaensis		+	+	+		
LOVI	Loxoconcha viva		+	+	+		+
MACO	*Macrocyprina okinawae*	+	+				+
MOTO	Moosella tomokoae			+			
MUNS	Munseyella sp.		+				
NEOL	Neonesidea oligodentata	+	+	+		+	+
NEOS	Neonesidea sp.	+	+				+
NIPD	Nipponocythere delicata		+	+	+	+	+
PAR1	Paracytherois sp.1		+				
PARO	Paijenborchella iocosa		+		+	+	
PDM	Pseudocythere cf moneroni	+					
PHAM	Phlyctocythere hamanensis		+	+			
PIBF	Pistocythereis bradyformis			+			
PIBR	Pistocythereis bradyi		+	+	+		
PKPS	Parakrithella pseudadonta		+	+	+		+
PKS1	Parakrithella sp.1		+		+		+
POCA	Pacambocythere humilitorus	+	+		+	+	
POSJ	Pontocythere subjaponica		+	+	+		+
POST	Pontocythere subtriangularis	+	+	+	+	+	
PROC	Propontocypris crocata	+			+		
ROBU	Robustaurila sp.	+	+		+		
SCHI	Schizocythere kishinouyei	+	+	+			+
SCLE	Sclerochilus semirutrens	+	+	+			
SEM1	Semicytherura sp.1 vit	+	+	+		+	
TOSP	Acanthocythereis sp.1		+				
TRA1	Trachyleberis sp.1	+	+	+	+		
TRA2	Trachyleberis sp.2		+	+			
TRAB	Trachyleberis scabrocuneata		+	+	+		+
TRAN	Trachyleberis niitsumai		+	+	+		
XESH	Xestoleberis hanaii	+	+	+	+	+	
XSES	Xestoleberis sagamiensis	+	+	+	+	+	+

No volcanic activity has been reported at any stations under the influence of the water mass a. Open sea species are associated with stations 146, 145 (Open sea environment, 213 and 145m deep, respectively), and with stations 137 and 143 (Mouth environment, 106 and 96m deep respectively). They are also found at the mouths of Japanese bays, sometimes in the bathyal environment. The Open sea water mass allows colonization of deeper species from the Open sea to the Bay Mouth environment. Some of these species, nevertheless, can adapt to inner bay conditions.

Frequent volcanic activities of Sakurajima give its originality to Kagoshima Bay. Volcanic ashes are favorable for the development of ostracod populations. In return, fumaroles and hotsprings decrease pH values of the water and severely restrict the development of ostracod populations. Although indices of the volcanic activity are reported at several stations, it does not seem that any species association is characteristic of this volcanic environment.

Although various industrial areas including farms and densely populated urbans are diffused around Kagoshima Bay, human pollution is not so much damaging ostracods and inputs of nutrients are of benefit to ostracods. In most of the stations under the influence of polluted water mass c, the abundance and diversity of ostracods are high. Stations under the influence of stagnant water masses b and d, which are more or less depleted of oxygen, are poor in ostracod species. Only some of them could adapt to these hostile and steady conditions. The Open sea water mass allows colonization of species from the Open sea environment into the bay. Some of them can adapt to inner bay conditions.

In Kagoshima Bay, the distribution of ostracod assemblages is largely controlled by the dynamics, structure and quality of water masses. These parameters have to be taken into consideration in paleoecological reconstructions.

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