Temporal changes of ostracode assemblages and anthropogenic pollution during the last 100 years, in sediment cores from Hiroshima Bay, Japan

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Abstract: Temporal changes of ostracodes during the last 100 years observed in three sediment cores from Hiroshima Bay, the Seto Inland Sea, Japan, provide valuable information about influences on ostracodes caused by anthropogenic pollution. This is the first detailed report of historical records of the relationship between ostracodes and pollution established from core samples drilled in the polluted inner bay. At least 38 ostracode species were identified from 40 samples. Based on biofacies, the density of ostracodes and the faunal structure, it is elucidated that industrialization combined with the effects of the second world war caused a decrease in the density and a increase in the equitability of ostracodes, and that anthropogenic pollution caused a simplification of ostracode assemblages in Hiroshima Bay. The response of two particular ostracode species to anthropogenic pollution is also demonstrated. *Callistocythere alata* was sensitive and *Bicornucythere bisanensis* has a strong resistance for anthorogenic pollution in ostracode species. Thus, the relative frequencies of these two ostracodes can be used as an indication of such pollution. We discuss the limitations of using recent ostracode assemblages in the analysis of the palaeoenvironment, resulting from the changes induced by anthropogenic pollution during the last 100 years.

Key words: Ostracoda, anthropogenic pollution, industrialization, second world war, heavy metal, nuclear testing, Cs-137 dating, radioactive fallout, Hiroshima Bay, western Japan.

Introduction

Ostracodes can be used as sensitive indicators of anthropogenic pollution, and this relationship has been studied by some authors (Bodergat, 1978; Kaesler *et al.*, 1979; Rosenfeld and Ortal, 1983; Bodergat and Ikeya, 1988; Bodergat *et al.*, 1997; Milhau *et al.*, 1997; Ruiz *et al.*, 1997; 2000; Mezquita *et al.*, 1999; Eagar, 2000; Rosenfeld *et al.*, 2000; Schornikov, 2000). Many of these studies concentrated on the spatial distribution of recent ostracodes in marine, brackish-water and freshwater environments. Schornikov (2000) reported that no living and/or dead ostracodes were found in heavily polluted areas in Vladivostok port, Russia. Ruiz *et al.* (2000) recognized that no ostracodes could be found in heavily polluted areas by surrounding mining and industrial activities in the Guadiana estuary, southwestern Spain. Rosenfeld *et al.* (2000) studied ostracodes and physicochemical factors in the Harod River, northern Israel, and suggested that some ostracode species could be used as indicators of pollution levels. They also recognized an inverse relationship between pollution levels and both ostracode species diversity and population density. However, there has been only one study of the relationship between vertical and historical changes in anthropogenic pollution levels and ostracodes in core samples (Ruiz Muñoz *et al.*, 1997). On the basis of analyses of three horizons in each of 12 cores excavated from the

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Huelva Estuary, southwestern Spain, Ruiz Muñoz *et al.* (1997) concluded that industrial pollution caused the local disappearance of ostracode species.

The aim of this project was to elucidate the history of impacts on ostracodes caused by anthropogenic pollution, using cores recovered from Hiroshima Bay, the Seto Inland Sea, western Japan. The Seto Inland Sea has been one of the inner bays polluted heavily by industrialization after the second world war in Japan, and was called 'Sea of death' around the 1960–70s. Also, red tides have been formed frequently. As a result of our research, new information regarding the use of ostracodes as indicators of anthropogenic pollution is provided.

Hiroshima Bay and the sediment cores

Hiroshima Bay is located in the western part of the Seto Inland Sea, western Japan, and close to Hiroshima City, which is a large city. There are many islands around Hiroshima Bay, which itself occupies an area of about 1058 km^2, and has a mean water depth of approximately 23.9 m. Two large rivers, the Ota and the Nishiki Rivers, flow into Hiroshima Bay. The Ota River is particularly polluted by the various industrial and domestic wastewater inflow (Kosaka, 1985). Since about 1960, Hiroshima Bay has been heavily polluted, and the water is often oxygen-deficient during the summer (Yuasa *et al.*, 1995). The concentration of heavy metals in the water of the Seto Inland Sea is several times higher than that in oceanic water (Oceanographic Society of Japan, 1985).

Sediment cores (cores H99–0, H99–1 and H99–2) were recovered from Hiroshima Bay (H99–0: 34°20′07″N, 132°29′00″E, 16 m water depth; H99–1: 34°18′00″N, 132°23′00″E, 21 m water depth; H99–2: 34°11′19″N, 132°21′02″E, 34 m water depth), the Seto Inland Sea, western Japan (Figure 1). These cores were taken with a Tripod corer (20 cm in diameter, 100 cm in length). Core lengths were 74 cm (H99–0), 65 cm (H99–1) and 50 cm (H99–2), respectively. The sediments of these cores are composed of homogeneous clay with pellets and shells. Many of the shells recovered were broken.

Materials and methods

Ostracode analysis

Samples of the sediment core, each 2–4 cm thick, were washed through a 75 μm sieve, oven-dried and dry-sieved into >125 μm fractions. Dry weights were calculated from the original sample weight, scaled by the percentage water content of each sample. Samples of the >125 μm fraction containing the abundant ostracode specimens were divided using a sample splitter into workable aliquots of approximately 200 specimens. In the remaining samples of the >125 μm fraction, all the specimens present were picked. The number of specimens refers to the sum of the number of left and right valves and carapaces.

Chemical analysis

Samples of the sediment core, sliced into 2 cm (0–50 cm core depth) or 3 cm (greater than 50 cm depth) thick sections, were dried at 105°C and homogenized using an agate mortar. An X-ray fluorescence analyser (XRF) RIGAKU RIX2000 (Rh cathod: 50kV-50mA) was used to measure the quantities of three elements (Cu, Zn and Pb) in the sediments following the procedures of Yamazaki *et al.* (2001). The level of Cs-137 in the sediments of cores H99–0 and 1 was analysed by gamma spectrometry following the procedures of Yamazaki *et al.* (1998) for the dating of core sediments.

Results

Ostracode biofacies

At least 38 ostracode species were identified from 40 samples obtained from cores H99–0, 1 and 2 (Table 1). The preservation of ostracodes was moderate and many specimens were opaque. A selection of these species is illustrated in Figure 2.

Q-mode cluster analysis was used to examine vertical changes in ostracode faunas and to determine ostracode biofacies, which we would expect to closely reflect variations in the depositional environment. Taxa represented by three or more specimens in any one sample were used for analysis, and each sample contained more than 50 specimens. Horn's overlap indices (Horn, 1966) were used to assess similarities, and clustering was achieved by the unweighted pair-group arithmetic average method. The result revealed three biofacies (AK, CS and BL; Figure 3).

Figure 4 shows the stratigraphic positions of biofacies and number of specimens per 10 g dry sediments of 13 taxa dominating each of the biofacies in these cores.

Biofacies AK (Ambtonia obai–Krithe japonica biofacies)

Biofacies AK is composed of six samples and lies in the lower part of core H99–2. It is characterized by the dominance of *Ambtonia obai* (Ishizaki), *Krithe japonica* Ishizaki and *Loxoconcha viva* Ishizaki. *Amphileberis nipponica* (Yajima) and

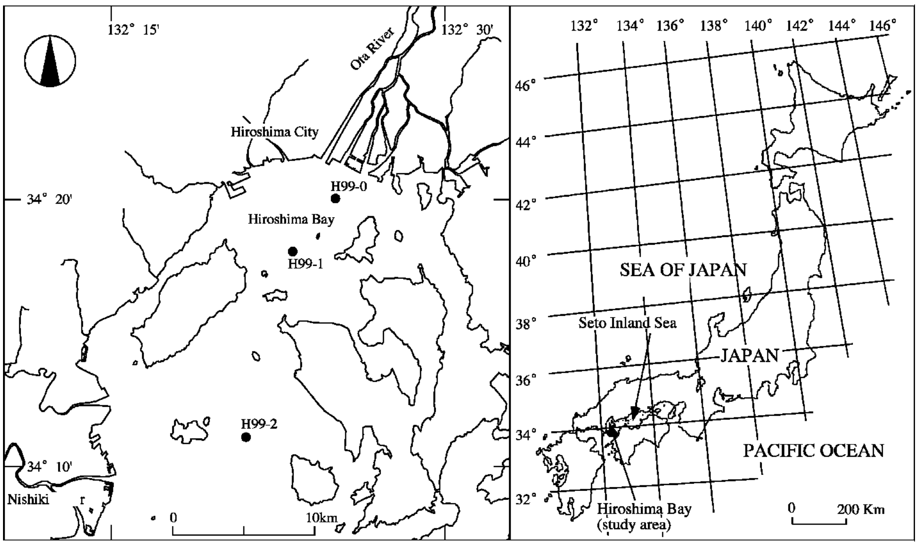
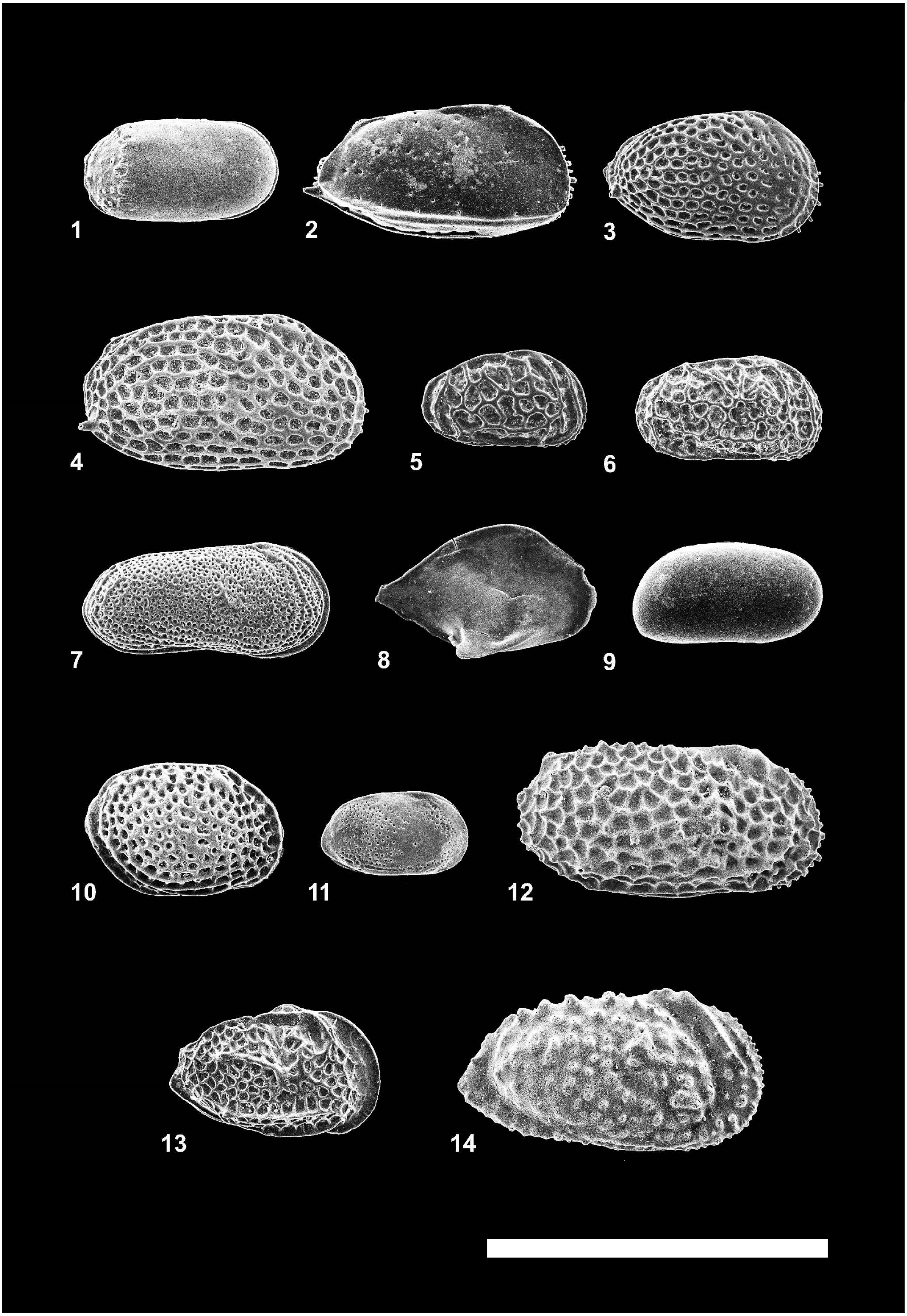


Figure 1 Index and locality maps.

Table 1 List of fossil ostracoda

	0-0	0-01	0-1	0-11	0-2	0-21	0-3	0-31	0-4	0-41	0-5	0-51	0-6	0-61	0-7	1-0	1-01	1-1	1-11	1-2	1-21	1-3	1-31	1-4	1-41	1-5	1-51	1-6	1-61	2-0	2-01	2-1	2-11	2-2	2-21	2-3	2-31	2-4	2-41	2-5
Ambtonia obai												1	2	1		1	1	2	2	5	6	5	16	8	9	15	8	22	6	2	2	9	11	19	9	16	12	17	24	10
Amphileberis nipponica																1	3	1	1				1	1	1	1		2		5	3	1	5	6	2	7	2	3	5	5
***Aurila spinifera* s.l.**																			1									2												
Aurila corniculata			1													3																						2		
***Aurila* sp.1**																													2							1				
***Aurila* sp.2**																															1									
Bicornucythere bisanensis		1	37	11	36	5	9	6	10	9	29	38	40	73	37	31	42	21	8	11	4	3	8	1	7	6	6	4	2	9	7	10		1				1		
***Bradleya* sp.**																												1												
Callistocythere alata	2		7		11	8	15	6	39	59	132	136	144	157	123	16	14	17	18	28	45	25	97	80	68	137	121	124	109											1
Callistocythere undulatifacialis							1									1	2	1	3		2		1	5	8	3	7	6	9											
Cytherois uranouchiensis																									1						1					1				
Cytheromorpha acupunctata	1		8	2	1	1	2		2	2	3	4	11	13	9	19	8	6	2	3	7	4	24	18	11	17	19	12	9	9	3	8	6	4			1	3		1
Cytheropteron kumaii																												1												
Cytheropteron miurense																	1						1																	
Hanaiborchella miurensis																											1													
***Hanaiborchella* sp.**																							1	1			1	1	3											
Kobayashiina donghaiensis																1	4			2			2	4	1		1	3	2					2		1		2	1	
Krithe japonica																10	10	13	6	11	8	1	10	8	15	7	16	26	10	2	2	7	6	27	6	30	6	17	11	11
Loxoconcha tosaensis									1	1			8	3	1										2															
Loxoconcha uranouchiensis																		1																						
Loxoconcha viva		2	21	2	17		8		3	2	2		11	17	9	25	49	33	25	9	4	6	25	16	20	27	13	35	34	15	12	23	11	6	2	21	5	18	11	9
***Microcythere* sp.**																	1																							
Munseyella oborozukiyo																								1			1		1											
***Munseyella* sp.**																		1	2			1		1		1														
Nipponocythere bicarinata																9	17	7	1	1	3		1	3	5	6	5	5	4	1	1	3	1	4	2	3	3	3	1	4
Paracytherois tosaensis																																1								
Parakrithella pseudadonta																		1															1							
Pistocythereis bradyformis		2					1			3		1	4	10	1	1	3	7	3	3	1	3	13	7	7	7	6	8	5	3	1	3	1	5	3	2	2	1	2	4
Pistocythereis bradyi														2		1	2		1	2			5	3	1	5	8	5	1		1	2	4	6	2	7	2	2	5	2
***Propontocypris* sp.**																																		1						
***Robustaurila* sp.**																																	1							
***Schizocythere* sp.**																											1													
Spinileberis quadriaculeata	5	1	8	1	6	2	4	1	7	1	11	14	25	24	14	11	11	11	6	12	6	8	30	13	11	16	15	28	23	18	4	13	3	7	4	3		6	4	6
Trachyleberis ishizakii																1	1		1	1				7	1		2	2												
Trachyleberis scabrocuneata					1		2		1		3	1	8	2		6	5	1	5	2	4	5	7	7	13	14	12	8		2		1								1
Xestoleberis hanaii																	1														1									
***Xestoleberis* sp.**																							1																	
Gen. et sp. indet.																				1																				
Total number of specimens	8	6	82	16	72	16	42	13	63	77	180	195	253	302	194	137	175	123	85	91	90	61	243	184	181	262	243	295	220	66	39	81	50	88	30	92	33	75	64	54
Total number of species	3	4	6	4	6	4	8	3	7	7	6	7	9	10	7	16	18	15	16	14	11	10	17	18	17	14	18	19	15	10	13	12	11	12	8	11	8	12	9	11
Number of specimens per 10g	2.6	3.2	16.9	7.0	11.7	4.9	7.0	4.6	10.8	24.6	34.4	38.6	42.7	63.8	40.2	45.9	39.4	36.6	30.4	28.9	30.2	20.3	58.6	46.8	57.7	55.1	64.1	58.4	44.0	16.5	13.3	14.3	13.9	22.7	7.9	18.7	9.9	13.7	16.5	15.1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Nipponocythere bicarinata (Brady) are also common. All of these species are abundant at water depths of more than 15–20 m in shallow sea areas around Japan (e.g., Ishizaki, 1971; Frydl, 1982; Bodergat and Ikeya, 1988; Yamane, 1998; Yasuhara and Irizuki, 2001).

Biofacies CS (Callistocythere alata–Spinilebetis quadriaculeata biofacies)

Biofacies CS is divided into two sub-biofacies. Sub-biofacies CS1 is composed of seven samples and lies in the lower part of core H99–0. It is characterized by the dominance of *Callistocythere alata* Hanai, *Bicornucythere bisanensis* (Okubo) and *Spinileberis quadriaculeata* (Brady). *Cytheromorpha acupunctata* (Brady) and *L. viva* are also common. All specimens of *B. bisanensis* in this study are 'form A' of Abe and Choe (1988), not including 'form M' of Abe and Choe (1988). *Bicornucythere bisanensis, S. quadriaculeata* and *C. acupunctata* are common in shallow inner bays around Japan (e.g., Ikeya and Shiozaki, 1993).

Sub-biofacies CS2 is composed of 10 samples and lies in the lower part of core H99–1. It is characterized by the dominance of *C. alata, L. viva* and *S. quadriaculeata. Cytheromorpha acupunctata, A. obai, K. japonica* and *N. bicarinata* are also common.

Biofacies BL (Bicornucythere bisanensis–Loxoconcha viva biofacies)

Biofacies BL is composed of eight samples and lies in the upper part of all three cores. It is characterized by the dominance of *B. bisanensis* and *L. viva. Spinilebetis quadriaculeata* are also common.

Density of ostracodes

The numbers of specimens per 10g dry sediments in each core are shown in Figure 4. In core H99–0, the number of specimens per 10 g dry sediments was generally high (24.6–63.8 specimens) in the lower part (46–74 cm depth, sample no. 0–41 to 0–61), and low (2.6–16.9 specimens) in the upper part (0–44 cm depth, sample no. 0–0 to 0–4). In the uppermost part (0–8 cm depth, sample no. 0–0 and 0–01), the number of specimens per 10 g dry sediments was extremely low (2.6–3.2 specimens).

In core H99–1, the number of specimens per 10 g dry sediments was generally high (44.0–64.1 specimens) in the lower part (36–65 cm depth, sample no. 1–31 to 1–61), and moderate (20.3–45.9 specimens) in the upper part (0–32 cm depth, sample no. 1–0 to 1–3). In the uppermost part of the core (0–12 cm depth, sample no. 1–0 to 1–1), the number of specimens per 10 g dry sediments increased towards the surface (i.e., 0 cm depth).

Throughout core H99–2, there were no remarkable changes in the number of specimens per 10 g dry sediments: it was generally low (7.9–22.7 specimens).

Figure 2 Scanning electron micrographs of fossil Ostracoda from sediment cores in Hiroshima Bay, western Japan. Scale bar = 1.0 mm. All specimens are adult right valves except a specimen of Figure 2–3 (A-1 instar right valve). (1) *Ambtonia obai* (Ishizaki) (sample no. 1–31); (2) *Amphileberis nipponica* (Yajima) (sample no. 1–01); (3) *Bicornucythere bisanensis* (Okubo) (sample no. 1–31); (4) *Bicornucythere bisanensis* (Okubo) (sample no. 1–41); (5) *Callistocythere alata* Hanai (sample no. 0–61); (6) *Callistocythere undulatifacialis* Hanai (sample no. 1–61); (7) *Cytheromorpha acupunctata* (Brady) (sample no. 1–51); (8) *Kobayashiina donghaiensis* Zhao (sample no. 1–2); (9) *Krithe japonica* Ishizaki (sample no. 1–51); (10) *Loxoconcha viva* Ishizaki (sample no. 1–5); (11) *Nipponocythere bicarinata* (Brady) (sample no. 1–51); (12) *Pistocythereis bradyformis* (Ishizaki) (sample no. 1–5); (13) *Spinileberis quadriaculeata* (Brady) (sample no. 1–31); (14) *Trachyleberis scabrocuneata* (Brady) (sample no. 1–41).

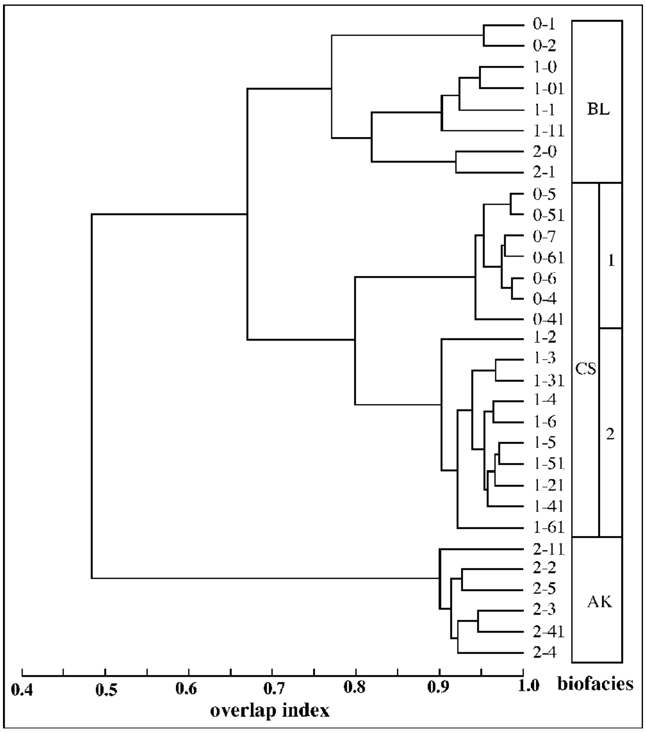

Figure 3 Dendrogram from Q-mode cluster analysis. AK, CS and BL show biofacies.

Species diversity and equitability

Species diversity can be expressed by the Shannon-Wiener formula: Diversity (H(S)) = $-\Sigma\ p_i \ln p_i$, where p_i is the proportion of the i-th species in a sample. Equitability was also calculated by using the equation of Buzas and Gibson (1969): Equitability (Eq.) = $e^{H(S)}/S$, S means the number of species. Only samples containing more than 50 specimens were used for these calculations. H(S), equitability and number of species in each core are shown in Figure 4.

In all cores, there were only small changes and no notable trends of values of H(S) and number of species. There were also only small changes of values of equitability in all cores. However, in cores H99–0 and 1, equitability shows similar trends. Values of equitability were relatively low (0.35–0.48 in core H99–0; 0.39–0.52 in core H99–1) in the lower part (40–74 cm depth, sample no. 0–4 to 0–61; 36–65 cm depth, sample no. 1–31 to 1–61), and high (0.61–0.69 in core H99–0; 0.49–0.66 in core H99–1) in the upper part (10–24 cm depth, sample no. 0–1 and 0–2; 0–32 cm depth, sample no. 1–0 to 1–3).

Heavy metal analysis

The vertical distributions of Cu, Zn and Pb in each core are shown in Figure 5. In all cores, the distributions of Cu, Zn and Pb show similar trends: the concentrations of these elements were generally low in the lower part, and high in the upper part.

In core H99–0, concentrations of the three elements were low in sediments at depths between approximately 45 cm and the bottom of the core. However, they increased rapidly from core depths of approximately 45 cm to 25 cm. In sediments at depths between approximately 25 cm and the surface, they show only small variations. Peak concentrations were found at the intervals of 10–12 cm (47.8 ppm), 12–14 cm (285.0 ppm) and 18–20 cm (57.9 ppm) in core depth.

In core H99–1, the concentrations of Zn and Pb were low in sediments at depths between approximately 30–35 cm and the bottom of the core. Concentrations of Cu were low in sediments at depths between approximately 40 cm and the bottom of the core.

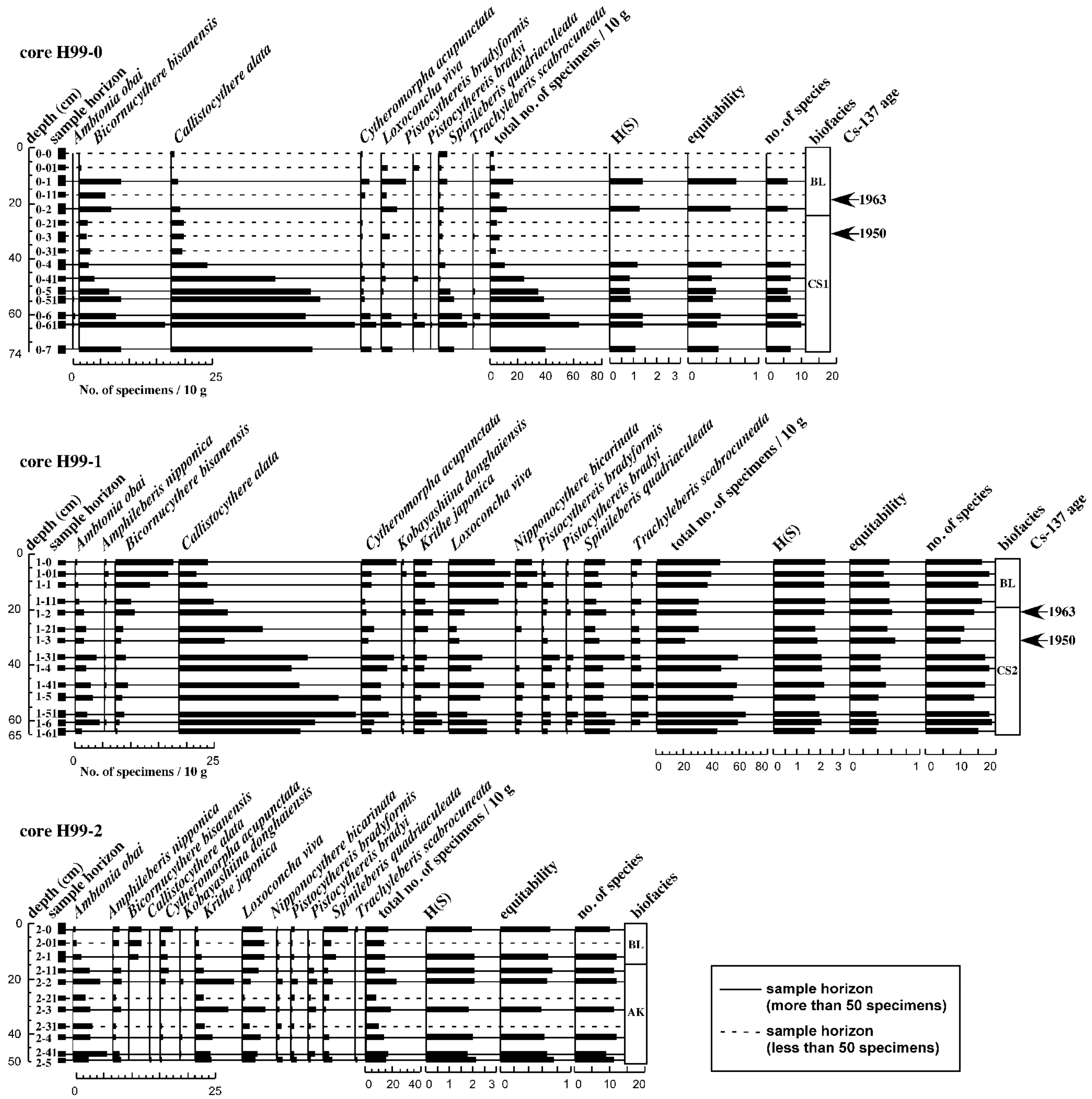

Figure 4 Diagrams showing sample horizons, Cs-137 ages, biofacies, number of specimens per 10 g dry sediments of dominant ostracode species, total number of specimens, Diversity (H(S)), equitability and number of species.

Zn and Pb concentrations increased rapidly between core depths of approximately 30–35 cm and 20 cm. Cu concentrations increased gradually from a depth of approximately 40 cm to the surface. From a core depth of approximately 20 cm to the surface, Zn and Pb gradually decreased. Peak concentrations were found at the intervals of 6–8 cm (39.6 ppm), 16–18 cm (256.0 ppm) and 16–18 cm (43.5 ppm) in core depth.

In core H99–2, concentrations of these elements were low in sediments at depths between approximately 25 cm and the bottom of the core. Zn and Pb concentrations increased rapidly from core depth of approximately 25 cm to 15 cm. Cu gradually increased from approximately 25 cm to the surface. In sediments at depths between approximately 15 cm and the surface, Zn and Pb show only small variations. Peaks concentrations of these elements were found at the intervals of 4–6 cm (31.7 ppm), 8–12 cm (171.0 ppm) and 8–10 cm (31.6 ppm) in core depth.

Cs-137 analysis

The vertical distributions of Cs-137 in cores H99–0 and 1 are shown in Figure 5. The distribution of Cs-137 is similar in both cores H99–0 and 1. Cs-137 was not detected in the lower part of either core (36–74 cm depth in core H99–0; 38–59 cm depth in core H99–1). Small spikes were observed at a depth of 34–36 cm in core H99–0 and 32–38 cm in core H99–1. The level of Cs-137 increased rapidly between depths of 30–32 cm (cores H99–0 and 1) and 18–20 cm (core H99–0) or 20–22 cm (core H99–1). Peaks were observed at depths of 18–20 cm in core H99–0 and at 20–22 cm in core H99–1.

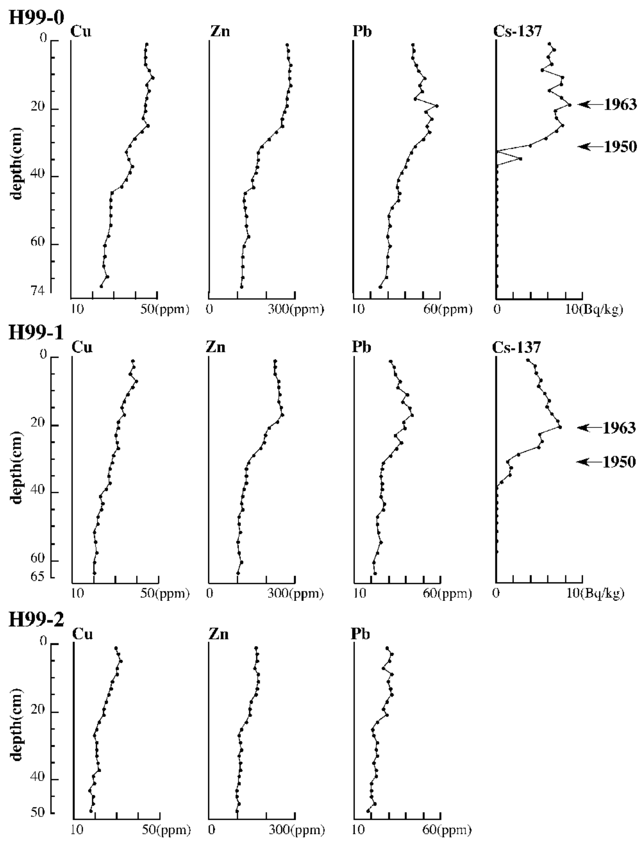

Figure 5 Vertical distributions of Cu, Zn, Pb and Cs-137.

Discussion

Cs-137 dating

The peaks located at depths of 18–20 cm in core H99–0 and 20–22 cm in core H99–1 are probably associated with the testing of nuclear weapons in 1963, which produced considerable atmospheric Cs-137 fallout (Figure 5). Horizons (30–32 cm depth in cores H99–0 and 1) in which Cs-137 begins to increase rapidly are probably correlated with *c*. 1950, because nuclear weapons testing had frequently been carried out from around this date. The small spikes below these horizons might have been caused by bioturbation or the nuclear bomb strike on Hiroshima City, Japan. The lack of Cs-137 at depths lower than these small spikes suggests an absence of Cs-137 exposure (i.e., before the second world war). This shows that correlation of horizons of 30–32 cm depth to the period of *c*. 1950 is correct to a high degree of probability. We assumed tentatively that the sedimentation rates were constant among Cs-137 dated horizons.

Ostracodes and anthropogenic pollutions

Ostracodes are known to be distributed in close association with various natural environmental factors such as surface substrate, water temperature, salinity and water depth. However, changes of these natural environmental factors cannot be recognized in the cores studied here on the basis of temporal changes of ostracodes and lithofacies. This result suggests that sediments including ostracodes in each core provide an accurate record of the impact of anthropogenic disturbance during the last 100 years. Changes in the concentrations of Cu, Zn and Pb reveal such disturbance: for example, wastewater from the city, and industrial and agricultural waste, which increased substantially after the industrialization of Japan (e.g., Matsumoto and Yokota, 1976; Hoshika *et al.*, 1983). It is thus possible to discuss the relationship between ostracodes and these heavy metals in the light of anthropogenic impact.

Ostracode densities, i.e., the number of specimens per 10 g dry sediments, decreased rapidly and values of equitability increased in approximately 1940 in core H99–0 and 1945–50 in core H99–1, although there was no notable change in core H99–2. This period coincides with a rapid increase in the concentrations of heavy metals. These results suggest that industrialization, together with the effects of the the second world war, caused a decrease in the density and a increase in the equitability of ostracodes in Hiroshima Bay and that the effect was stronger and took place more rapidly in the enclosed inner part of the bay (site H99–0) than at the deep-water site (H99–1). Pollution did not cause a decrease in the density and an increase in the equitability of ostracodes in the middle bay area (site H99–2), consistent with the result that concentrations of heavy metals decrease between the inner part of the bay (site H99–0) and the middle bay area (site H99–2). Decreasing of ostracodes caused only in the inner part of the bay is also consistent with the report that remarkable pollution was caused after the 1950s in the Seto Inland Sea (e.g., Kosaka, 1985). At site H99–1, the trend is reversed from the 1980s (sample no. 1–0 to 1–1), with ostracode densities increasing and the concentrations of Zn and Pb decreasing during the same period. The same trend was recognized during the 1960s–70s (sample no. 0–1 to 0–2) in core H99–0. Several legal regulations against pollution have been carried out after about 1970 in the Seto Inland Sea (e.g., Kosaka, 1985). These results suggest that anthropogenic pollution and its influence on ostracode densities were gradually reduced, and that this effect was realized more quickly in the enclosed inner part of the bay (site H99–0) than at deep-water sites (H99–1). Further pollution might have caused an additional decrease in ostracode numbers at site H99–0 after the 1980s (sample no. 0–0 to 0–01), but this effect is still to reach site H99–1.

Different ostracode biofacies and sub-biofacies were distributed in the lower part of all cores, which represent the period before approximately 1955 in core H99–0 and 1960 in core H99–1. These differences probably depend on the water depth, because the abundance of deep-bay species (more than 15–20 m water depth) increased and of shallow inner-bay species decreased from the shallow site (H99–0) to the deep site (H99–2). However, after this period, the same ostracode biofacies were found to be distributed among all sites. During this period, the concentrations of heavy metals (all heavy metals in H99–0; Zn and Pb in H99–1 and 2) reached almost their maximum values at all sites. Since the early 1960s, the oceanic waters of Hiroshima Bay have been heavily polluted and oxygen-deficient (Yuasa *et al.*, 1995). It therefore seems highly probable that anthropogenic pollution caused the reduction in diversity of ostracode assemblages in approximately 1955 in the region around core H99–0 and 1960 in the locality of core H99–1, the effects of pollution becoming apparent more quickly in the enclosed inner bay than at the deep-water sites.

Figure 6 shows the vertical changes of the relative abundance of *C. alata* and *B. bisanensis* in cores H99–0, 1 and 2. Before approximately 1940 (sample no. 0–4 to 0–7) in core H99–0 and 1960 in core H99–1 (sample no. 1–21 to 1–61), the relative abundance of *C. alata* was extremely high. After approximately 1955 (sample no. 0–1 and 0–2) in core H99–0 and 1960 in core H99–1 (sample no. 1–21 to1–61), however, the relative abundance of *C. alata* decreased rapidly, and *B. bisanensis* increased: this increase is also recognizable in the upper part of core H99–2 (sample no. 2–0 to 2–1). These results suggest that *C. alata* was sensitive and that *B. bisanensis* has strong resistance to anthropogenic pollution in ostracode species, and raises the possibility that they can be used as pollution indicator species. The extremely low relative abundance of *B. bisanensis* in the uppermost part of core H99–0 was probably a statistical artifact caused by the small number of ostracode specimens that reflect some serious pollution, as mentioned above.

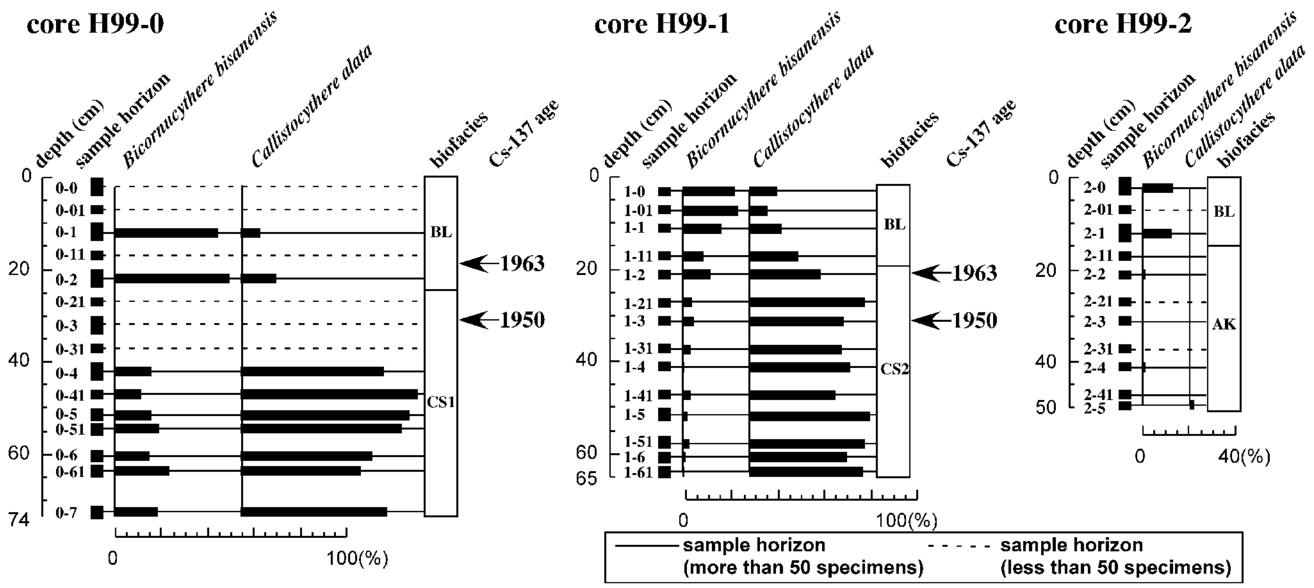

Figure 6 Vertical changes of the relative abundance of *C. alata* and *B. bisanensis*.

Ikeya and Shiozaki (1993) showed that *B. bisanensis* is common at water depths ranging from 2 to 16 m in Japanese inner bays. However, in this study, it was dominant in the upper part of cores H99–1 (21 m water depth) and H99–2 (34 m water depth). Yasuhara and Irizuki (2001) and Yamane (1998) reported that *B. bisanensis* was common at water depths ranging from 9.2 to 37.2 m and 4.1 to 36.0 m in Osaka Bay and Hiuchi-nada Bay, the Seto Inland Sea, Japan: areas that are highly polluted by industrial and domestic wastewater. Tanaka *et al.* (1998) and Takayasu *et al.* (1990) reported that *B. bisanensis* came to be dominant in almost all areas of Nakano-umi Bay, western Japan, following dam construction for the drainage and reclamation of land. These results show that *B. bisanensis* extends its distribution in polluted areas, because of its comparatively strong resistance to anthropogenic disturbance and pollution. In other words, it is able to exploit niches that become available as a result of the local extinction of pollution-susceptible species, even though naturally vacant niches might not be suitable. There have been many studies of the recent distributions of ostracodes in various areas of Japanese inner bays (Ishizaki, 1968, Uranouchi Bay; Ishizaki, 1969, Nakano-umi Bay and Shinji Lake; Ishizaki, 1971, Aomori Bay; Ikeya and Hanai, 1982, Lake Hamana; Frydl, 1982, Tateyama Bay; Bodergat and Ikeya, 1988, Ise and Mikawa Bays; Takayasu *et al.*, 1990, Nakano-umi Bay and Shinji Lake; Ikeya and Itoh, 1991, Sendai Bay; Ikeya *et al.*, 1992, Otsuchi Bay; Itoh, 1998, Lake Hamana; Tanaka *et al.*,1998, Miho Bay to Lake Shinji; Yamane, 1998, Hiuchi-nada Bay; Yasuhara and Irizuki, 2001, Osaka Bay). However, there is only one site in Japan where *C. alata* is the dominant species. In most sites, *C. alata* is rare or absent. Therefore, in some of these sites, *C. alata* has probably disappeared or been substantially decreased under the influence of anthropogenic pollution. Consistent with this result is the fact that all samples used in these studies were collected after 1960, with the exception of some samples taken by Ishizaki (1968). These interpretations regarding the distribution of *B. bisanensis* and *C. alata* based on previous studies are confirmed by the results obtained in the present study.

As mentioned above, we should recognize that analyses of the palaeoenvironment based on the distributions of recent ostracodes have some limits, because ostracode assemblages have been radically changed by anthropogenic pollution during the last 100 years.

Conclusions

Core sediments excavated from muddy inner bays, such as those used in this study, are suitable as samples from which to elucidate the impacts to ostracode distribution caused by anthropogenic pollution. Because various natural environmental factors are more stable in inner bays than in river mouths and estuaries, historical changes can be continuously observed at the same site. Temporal changes of ostracode assemblages in cores H99–0, 1 and 2 excavated from Hiroshima Bay, western Japan, therefore provide valuable information about the impact on their distribution caused by anthropogenic pollution, including the following points.

First, the rapid increase of industrialization during the 1940s, combined with the effects of the second world war, caused a decrease of density and a increase of equitability of ostracodes in Hiroshima Bay, the Seto Inland Sea, Japan, and the effect was stronger and acted more quickly in the enclosed inner part of the bay (site H99–0) than at the deep-water site (H99–1). Pollution did not cause any noticeable decrease in ostracode numbers in the middle bay site (H99–2). During the 1960s and 1970s in core H99–0, and after the 1980s in core H99–1, anthropogenic pollution and its effect on ostracodes were probably gradually reduced, and this effect was more rapidly apparent in the enclosed inner part of the bay (site H99–0) than at the deep-water site (H99–1).

Second, anthropogenic pollution caused the simplification of ostracode assemblages in about 1955 in core H99–0 and 1960 in core H99–1, and this effect was more rapid in the enclosed inner part of the bay (site H99–0) than at the deep-water site (H99–1).

Third, *C. alata* was sensitive to anthropogenic pollution, whereas *B. bisanensis* has strong resistance in ostracode species. The relative proportions of *C. alata* and *B. bisanensis* in a sample can therefore be used as indicators of the degree of pollution. *Bicornucythere bisanensis* has been able to extend into niches vacated by ostracode species that are susceptible to pollution, thus increasing its local distribution. However, naturally vacant niches appear unsuitable for exploitation by *B. bisanensis*, implying that it competes with *C. alata*, and that its ability to withstand anthropogenic stress allows it to inherit niches that were formerly occupied by the latter. In some areas of Japan, *C. alata* populations have probably disappeared completely or been significantly decreased as a result of pollution.

Fourth, analyses of the palaeoenvironment based on the distributions of recent ostracodes are of limited value, because of the changes in ostracode assemblages that have resulted from anthropogenic pollution during the last 100 years.

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