REPORT SERIES 5a

Trace Metals in Sediments, Indicator Organisms and Traditional Seafoods of the Torres Strait

GREAT BARRIER REEF
MARINE PARK AUTHORITY

Commonwealth
Coastal Action Program

Trace Metals in Sediments, Indicator Organisms and Traditional Seafoods of the Torres Strait

William Gladstone
Great Barrier Reef Marine Park Authority

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Community Information Unit
Department of the Environment,
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GPO Box 787
Canberra ACT 2601

Toll free: 1800 803 772
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Great Barrier Reef
Marine Park Authority
PO Box 1379
Townsville Qld 4810

Phone: (077) 500 700
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For further information about this report contact Jon Brodie, Director, Research and Monitoring, Great Barrier Reef Marine Park Authority, phone (077) 500 700.

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SUMMARY AND RECOMMENDATIONS

1. The Torres Strait Baseline Study (TSBS) was initiated by the Australian Government in response to the concerns of Torres Strait Islanders, scientists and fisherfolk about the possible effects on the Torres Strait marine environment from mining operations in the Fly River catchment of Papua New Guinea. The Study began in 1990. The scientific program commenced with a Pilot Study which undertook a preliminary assessment of the levels, and sources, of trace metals in Torres Strait, investigated several species of marine organisms for use as indicators of trace metal levels in the marine environment, and assessed levels of trace metals in seafoods commonly eaten by Torres Strait Islanders. The results of the Pilot Study were used to design a more comprehensive and broadscale Main Study, which was undertaken in the Torres Strait in 1992-93. It is the results of the Main Study which are reported here.

2. This report provides information on the trace metal content of sediments, indicator organisms, and some of the traditional seafoods of the Torres Strait.

3. The Study concluded that the influence of the Fly River on the trace metal levels and content of sediments and selected indicator organisms was limited to the northern Torres Strait. Other, smaller coastal rivers of Papua New Guinea influence the trace metal content of sediments in the north of the central Torres Strait. Levels of trace metals in locations influenced by the Fly River were less than levels reported from polluted regions, and comparable to levels found in unpolluted locations on the Great Barrier Reef. High levels of some trace metals, including cadmium, were found in some seafoods commonly eaten in the Torres Strait and warrant attention by health authorities. These high levels appear to be unrelated to human activities.

4. Marine sediments in the Torres Strait contain a suite of trace metals derived from different sources. Trace metals derived from mainland Papua New Guinea (from the Fly River and smaller coastal rivers) include aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead and zinc. Levels of these metals are highest in fine-grained sediments in the northern Torres Strait near the mouth of the Fly River and close to the Papua New Guinea coastline. A number of these trace metals occur in higher concentrations in sediments coming from the Fly River, including aluminium, copper, mercury, nickel and zinc.

5. Cadmium in Torres Strait sediments is derived from marine sources: concentrations are highest in coarse-grained sediments with a high calcium carbonate content from the central and eastern Torres Strait. Selenium was not associated with either marine or land-based sources and concentrations were similar throughout the Torres Strait.

6. Sediments from the Fly River penetrate only a small distance into the Torres Strait, possibly to a line from just north of Bramble Cay (9°08.5'S, 143°50.1'E) to the northern end of the Great North-East Channel (9°13.5'S, 143°29.9'E).

7. Levels of cadmium, copper, lead and zinc in sediments reported in this study for the Torres Strait and mouth of the Fly River were similar to levels found in comparable, unpolluted locations in the tropics, and less than levels reported from similar areas regarded as contaminated.

8. The trace metal content of sediments in the northern and central parts of the Torres Strait west of the Warrior Reefs appears to be influenced by smaller rivers along the Papua New Guinea coastline, and not the Fly River. The influence of these smaller coastal rivers on the Torres Strait is limited, possibly extending only to the area west of Moon Passage (around 9°35.0'S, 142°47.0'E).

9. Levels of trace metals in sediments collected during the Main Study (1992-93) were similar to levels reported from the Pilot Study (1991-92). And, levels of trace metals reported in the present study were similar to levels reported in other earlier studies (1989-90) from similar locations in the Torres Strait and from near the mouth of the Fly River.

10. Two species of marine molluscs were collected as indicators of trace metals in the surrounding environment: the burrowing clam *Tridacna crocea* and the mangrove cockle *Polymesoda erosa*.

11. The levels of particular trace metals in burrowing clams was largely influenced by their location in the Torres Strait. Burrowing clams in the northern Torres Strait had higher levels of cadmium, copper, lead, manganese, mercury, silver and zinc. In the central and eastern Torres Strait burrowing clams had higher levels of arsenic, cobalt, iron, selenium, strontium and uranium. Chromium and nickel were highest in clams in the southern Torres Strait; aluminium was highest in clams from both the northern and southern Torres Strait.

12. Amongst reefs in the Torres Strait where burrowing clams were sampled, Bramble and Kokope Reefs were the most consistently influenced by water from the Fly River. Levels of copper in burrowing clams from these two locations were either less than, or equal to, copper levels in burrowing clams collected from similar locations on the Great Barrier Reef regarded as being unpolluted.

13. Levels of many trace metals in burrowing clams changed from the pre-monsoon to monsoon season: cobalt, copper, iron, nickel, selenium, strontium and uranium dropped from the pre-monsoon to monsoon at all stations; aluminium, manganese and lead also dropped from the pre-monsoon to monsoon season but not at all stations; zinc levels increased at all stations between the pre-monsoon and monsoon seasons; mercury also increased over the same time but not at all stations. Levels of arsenic, cadmium, chromium and silver did not change between seasons.

14. There was little correspondence in the relative levels of trace metals between burrowing clams and sediments which had been collected from similar locations in the Torres Strait. The only exceptions to this were copper, lead, manganese, mercury, selenium and zinc. Corresponding spatila trends in the levels of these metals were detected in both burrowing clams and sediments, in both seasons.

15. Seasonal changes in the levels of most trace metals in burrowing clams did not reflect the seasonal changes which were recorded in sediments collected from similar locations. Only four metals (cadmium, nickel, selenium and zinc) underwent similar changes between seasons in burrowing clams and sediments.

16. The complexity of the results for burrowing clams indicate that trace metal levels are a product of the environmental levels of metals, and some other environmental variable (e.g. salinity, water temperature, pH). This has implications for their use as indicators of environmental levels of trace metal levels in monitoring programs in locations where these variables undergo considerable changes.

17. Patterns in trace metal levels in mangrove cockles were variable and influenced to a greater extent by local variability in trace metal levels rather than their proximity to the major terrigenous sources of trace metals.

18. The trace metal content was assessed in a wide range of seafoods commonly eaten by Torres Strait Islanders, including fishes (fifteen species), molluscs (one species), crustaceans

(two species), green turtle and dugong. The majority of species had low levels of trace metals, when compared with established standards. The exceptions to this were:

- single specimens of parrotfish (high levels of cadmium and copper) and barramundi (high levels of mercury);
- boiled crayfish heads (high cadmium levels);
- dugong liver (high levels of cadmium, copper, selenium, zinc and possibly mercury); dugong kidney (high levels of cadmium and selenium); dugong intestine (high levels of cadmium); and
- turtle liver (high levels of cadmium, copper, mercury, selenium); turtle kidney (high levels of cadmium, selenium and possibly mercury); turtle intestine and muscle (high levels of mercury).

19. Established health standards for cadmium are exceeded by weekly consumption of relatively small quantities of crayfish hepatopancreas (between 79 and 222 g per week), dugong liver (17-47 g), dugong kidney (13-37 g), turtle intestine (29-82 g), turtle kidney (6-11 g), and turtle liver (10-28 g). Current consumption patterns of these foods in the Torres Strait are unknown.

20. Elevated levels of cadmium in turtle and dugong tissues are not unique to the Torres Strait. Similarly high levels occur in dugong from other parts of Queensland, and in green turtles from Hawaii.

21. Cadmium occurs naturally in Torres Strait marine sediments, with the highest levels occurring in coarse-grained sediments with a high calcium carbonate content.

Recommendations

The following actions are recommended, as a consequence of the results of this Main Study.

1. Undertake a long-term monitoring program for trace metal levels in the sediments and selected indicator organisms of the Torres Strait marine environment. The principal aim of this monitoring program will be to:

- gather long-term data on levels of trace metals in the sediments and selected indicator organisms of the Torres Strait, and the characteristics of sediments, in a way that will allow for the reliable detection of trends over time that could be associated with human activities.

1.1 Fulfil the principal aim of the monitoring program by following the sampling design used in the present study, with the following changes:

- examine alternative means of monitoring at Bramble and Warrior Reefs because of potential difficulties in obtaining sufficient numbers of burrowing clams (e.g. investigate the use of transplanted clams);
- collect mangrove cockles of a similar size/age range (e.g. 60-70 mm shell length) from the same localities;
- initiate community and scientific discussions on whether the extent of changes in trace metal content and sediment characteristics that are detectable through the current sampling program are acceptable, and amend the sampling program if necessary.

1.2 Continue monitoring at three yearly intervals. The monitoring program should therefore begin in the pre-monsoon season of 1995 (i.e. three years after sampling for the present study was undertaken).

1.3 The Great Barrier Reef Marine Park Authority to coordinate and undertake this monitoring program (because of the networks and expertise established during the course of the Baseline Study).

2. Survey the consumption rates of seafoods (especially dugong and turtle) and other foods by Torres Strait communities at different locations, and over an extended period of time. As a parallel initiative, this survey should be extended to include north Queensland coastal Aboriginal communities. Use these results, with the results on trace metal content, to assess the health implications of consuming large quantities of dugong and turtle.

3. Undertake a community education program at all island communities throughout the Torres Strait and coastal Papua New Guinea, to explain the results of this Study and the potential health implications. This program should be team-based and include a representative of the Great Barrier Reef Marine Park Authority familiar with the results of the Study, a Torres Strait Islander familiar with the Study and most island communities and a Torres Strait health worker.

4. Convey the results of this Study, and the potential health implications of the seafood study, to north Queensland coastal Aboriginal communities.

5. Analyse the remaining dugong and turtle samples, to reduce the variability in the estimates of levels of metals in these food items, as a means of improving public health advice and planning. Analyse additional samples of fish species where trace metal levels where high, but only a limited numbers of specimens were tested e.g. barramundi, parrotfish and Murray Island sardines.

6. Analyse whole, cooked hepatopancreas from crayfish, as it is known that this is now more regularly eaten in the Torres Strait.

7. Undertake additional statistical analysis of data on the trace metal content of sediments to incorporate the revised arsenic results, and also the effect of grain size variation on the spatial and temporal patterns of trace metals in sediments.

BACKGROUND TO THIS REPORT

In July 1989 the then Prime Minister of Australia, the Rt Hon. RJL Hawke MP, announced, as part of his statement on the environment (Our Country, Our Future) that the Australian Government would fund a four year environmental study of the Torres Strait marine environment. This study, later called the Torres Strait Baseline Study, was instigated in response to concerns expressed by Torres Strait Islanders, commercial fishermen and scientists, about possible effects on the marine environment of the Torres Strait from mining operations in the Fly River catchment area of Papua New Guinea.

The Baseline Study had four component programs investigating various aspects of trace metals in the Torres Strait marine environment: (1) trace metals in sediments (2) trace metals in biota (3) trace metals in seafoods commonly eaten by Torres Strait island communities, and (4) trace metals in the commercial seafood catch of the Torres Strait. The last program was undertaken by a consultant and will be reported separately.

The scientific components of the Study began with a Pilot Study in 1991-1992 designed to: (1) identify species of biota which would reflect levels of heavy metals in the Torres Strait marine environment (i.e. indicator organisms), and (2) undertake preliminary assessments of the levels of heavy metals in the biota, sediments and traditional seafoods of the Torres Strait.

The results of the Pilot Study were published in 1993[1] and were used to design a much broader Main Study (which was subsequently carried out in the Torres Strait in 1992-1993). A lack of funding prevented the completion of the Main Study during 1993. Funding was subsequently made available under the Strategic Initiatives Program from the Department of Prime Minister and Cabinet in 1994-95, on behalf of the Minister for Aboriginal and Torres Strait Islander Affairs, to allow for the chemical analysis of samples collected for the Main Study, and the preparation of a report on the results. This document is a report of those results.

[1] Dight I. J. and Gladstone W. 1993, *Torres Strait Baseline Study: Pilot Study Final Report June 1993*, GBRMPA Research Publication No. 29, Great Barrier Reef Marine Park Authority, Townsville.

1. TRACE METALS[2] IN TORRES STRAIT SEDIMENTS

BACKGROUND

The Pilot Study of the Torres Strait Baseline Study (TSBS) concluded that the Fly River is the major source for the northern Torres Strait of fine-grained terrigenous sediments with an associated suite of trace metals (including aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silicon and zinc), some of which increased in concentration after the monsoon season (Dight and Gladstone 1993). Concentrations of metals within this suite are low in the central and eastern Torres Strait. Other trace metals in Torres Strait marine sediments occurred at higher concentrations in either sediments with coarse-grained carbonate sediments of marine origin (cadmium, magnesium), or were not associated with any particular sediment type (arsenic, mercury and selenium).

There were, however, two inconsistencies in this data: (1) few of the trace metals originating from the Fly River (except cobalt, nickel and silicon) increased in concentration in the post-monsoon sampling. This is despite several recent oceanographic studies which have indicated that brackish water and sediments from the Fly River intrude further into the Torres Strait during the monsoon period (December-March) when winds are predominantly from the north-west (references by Wolanski et al 1992a,1992b, 1992c, 1992d); (2) some Fly River associated metals were in higher concentrations in the western Torres Strait, and their concentrations increased in the monsoon season, suggesting an additional source of trace metals for the Torres Strait (possibly Irian Jaya or western Cape York). These inconsistencies were addressed in the design of the Main Study.

The Pilot Study also concluded that the concentrations of cadmium, copper and zinc in Torres Strait sediments (including those in one sampling location inside the Fly River delta) were similar to those recorded by earlier studies in the Torres Strait, and they all fell within the levels which had been recorded from unpolluted tropical coastal areas elsewhere (Dight and Gladstone 1993).

A more comprehensive sampling program was designed for the Main Study, the objectives of which were to:

(1) sample from additional locations in the north-western Torres Strait near the Papua New Guinea coastline to identify other possible sources of trace metals into the Torres Strait;
(2) assess the extent of Fly River influence on the Torres Strait by sampling from a greater number of stations as early as possible in the monsoon season; and
(3) provide a baseline of information on concentrations of trace metals in sediments from a wide area of the Torres Strait against which future trends can be assessed.

METHODS AND MATERIALS

Sample Collection and Storage

Sediment samples were collected, using a Smith-McIntyre stainless steel grab, from the stations shown in figure 1.1[3] (as recommended by Dight and Gladstone 1993) between 8 October and 1

[2] Following Rainbow (1988) the term 'trace metal' will be used synonymously throughout this report with the term 'heavy metal' to include both the essential metals (As, Cr, Co, Cu, Fe, Mn, Ni, Se, Sn, Zn) and the non-essential metals (Ag, Cd, Hg, Pb).
[3] Figures and tables referred to in the text are included at the end of the chapter, in the order to which they are referred in the text.

November 1992 (pre-monsoon season) and between 7 and 19 March 1993 (monsoon season). Each station was a circle of radius 500 m within which three sites were chosen by a process of randomly selecting a distance and bearing from the centre of the site; three replicate grab samples were collected in each site (i.e. a total of nine replicate grab samples per station). The latitude and longitude of each site was recorded with GPS and the depth was recorded from the ship's depth sounder. All sampling and sample storage was done aboard the Ok Tedi Mining Ltd research vessel 'Western Venturer'.

After the grab was retrieved to the ship's deck the excess water was allowed to drain then the sample was deposited on a plastic dish. This was transferred to the ship's laboratory where sub-sampling was done in a laminar flow hood. Sub-samples were collected from the surface of the sample to a depth of 5 cm using plastic corers of diameter 2.5 cm. Five replicate sub-samples were taken and combined in a plastic container to form a single replicate sample. Surgical gloves were worn while sub-sampling and transferring sub-samples to plastic containers. Each sample was immediately frozen and remained frozen until transfer to the laboratories of the Queensland Department of Primary Industries (Agricultural Chemistry) in Brisbane. All plastic containers (the dish used to collect sediment from the grab; the corer; the sample containers) were washed in 10% nitric acid prior to use and stored in clean plastic bags. The collecting dish and the corer were washed in Reverse Osmosis Polished water (prepared by the procedure described in appendix 7) between samples and at the end of each site's sampling.

Surface salinity was recorded (using a YSI Model 33 S-C-T Meter; YSI Incorporated, Yellow Springs Ohio) at the same time as sediment samples were being collected. During the recording of surface salinity the probe was held just below the water surface at a depth of 15-30 cm.

Trace Metal Analysis

All samples were analysed by Queensland Department of Primary Industries' (Agricultural Chemistry) laboratory in Brisbane. This laboratory successfully participated in the National Oceanic and Atmospheric Administration (NOAA) Eighth Round Inter-comparison for Trace Metals in Marine Sediments and Biological Tissues.

Procedures followed are outlined in detail in appendix 1.

NB: Results reported and discussed here for arsenic were analysed by different methods in each season: pre-monsoon samples were analysed by hydride generation atomic absorption spectrometry (AAS) and monsoon samples were analysed by X-ray fluorescence (XRF). In a second round of analyses the monsoon samples were re-analysed by AAS, however it was not possible to include the revised results in the statistical analysis which had already been done for this chapter. They are included in this report as appendix 2. Although the AAS absolute results were higher for the same samples than those results obtained using XRF, the inter-station patterns appear to be similar. Accordingly, the results for seasonal comparisons of arsenic reported later in this chapter are not a valid comparison and should be treated cautiously. Additional statistical analysis is required on the revised arsenic results.

Statistical Analysis

A combination of descriptive exploration, univariate analysis of variance (ANOVA) and canonical discriminant analysis (CDA) were used. ANOVA and CDA were undertaken after metal concentrations had been transformed to their natural logs. Visual inspection of the normality and homogeneity of variances (Underwood 1981) indicated that these were improved after natural log transformation.

CDA was done for all metals from all stations (i.e. the results for each metal were pooled for each station) in each season and inspected visually on a reduced plot of the first two canonical variates. The influence of each metal on the trends depicted in the reduced plot was derived from plots of both their canonical coefficients and structural coefficients. Metals having a strong influence on trends depicted in the reduced plots have canonical and structural coefficients which are high, and situated at similar locations on both plots. Metals which displayed contradictory results for the canonical and structural coefficients are regarded as being less influential on trends depicted in the reduced plots.

ANOVA was done on individual metals to test the null hypothesis that the metal level did not vary between seasons, stations and sites within stations. F ratios and variance components were constructed using the formulae shown in appendix 6. Variance components were calculated after preliminary examination of the ANOVAs revealed that for many metals there was a significant effect of site. Although F ratios can be statistically significant for such nested factors, they can be chemically meaningless. Calculations of the total variance explained by each factor (Underwood 1981) is a useful way of checking the magnitude of these effects.

Calculations of a large number of ANOVAs on the same data set increases the likelihood of a Type I error (Underwood 1981). This can be compensated for by calculating an adjusted alpha significance level (Day and Quinn 1989). In this case an adjusted alpha signifciance level was calculated by the Dunn-Sidak method (Day and Quinn 1989) where $\alpha_{adj} = 1\text{-}0.95^{1/r}$, and r = 15 (the number of metals tested), i.e. $\alpha_{adj} = 0.003$. F ratios are significant when their p value is less than 0.003 (not the usual 0.05).

RESULTS

Seasonal and Spatial Patterns in Surface Salinity

Patterns in surface salinities during the pre-monsoon and monsoon seasons were complex (figure 1.2). During the pre-monsoon season (October-November 1992) surface water of lower salinity (from 27.0 to 30.2 ‰) extended from the mouth of the Fly River (at S1) southward from S6 through the Great North-East Channel to S17 (relative to waters to the east where salinity varied from 31.0 to 33.0 ‰, and to waters to the west of the Warrior Reefs at S18 where salinity varied from 32.2 to 33.9 ‰). Lower salinity surface water also extended westward from the mouth of the Fly River along the Papua New Guinea coastline to S11 (over which salinity varied from 27.0 to 30.0 ‰).

During the monsoon season (March 1993) there was a narrow band of lower salinity surface water (from 29.5 to 30.8 ‰) between the mouth of the Fly River and along the Papua New Guinea coastline (figure 1.2). Surface salinities in the Great North-East Channel (32.0-32.1 ‰) and to the west of the Warrior Reefs (31.8-32.0 ‰) were slightly greater than the coastal salinities, but less than salinities in the eastern reefs (32.9-33.3 ‰).

Surface salinities recorded during the pre-monsoon season were usually less than those recorded during the monsoon season (figure 1.2). The only exceptions to this trend were stations to the west of the Warrior Reefs where surface salinities during the pre-monsoon season were greater than during the monsoon season.

Physico-Chemical Properties of Sediments

Torres Strait sediments varied widely in their physico-chemical properties (appendix 3). Sediments from station S1 at the mouth of the Fly River had the highest proportion (38.3%) of fines (i.e. < 63 µm), and showed a significant increase during the monsoon season. This station also had the smallest amounts of coarse material. Station S12 along the Papua New Guinea coastline had a similar proportion of fines (37.1%) in the pre-monsoon season, but this was not associated with a similarly large amount of less fine material (10.9% of the < 63 µm-200 µm class); the proportion of fines did not increase in the monsoon season at this station, suggesting that there may be considerable spatial variation in sediment characteristics there. The amount of fines in other stations close to the mouth of Fly River (S6, S15) and along the Papua New Guinea coastline (S8, S10, S11, S13) was similar to stations in the central (S5, S18) and eastern Torres Strait (S7, S14). There were higher amounts of fines in stations in the Great North-East Channel (S16, S17), but they displayed minor changes between seasons.

Sediment organic carbon content (appendix 3) was highest at S1 at the mouth of the Fly River, and decreased in the following progression: stations along the Papua New Guinea coastline (S8, S10, S11, S12, S13), stations in the northern Torres Strait (S6, S15), stations in the central Torres Strait (S5, S16, S17, S18), stations in the eastern reefs (S7, S14). The greatest increase in sediment organic carbon content from the pre-monsoon to monsoon seasons (from 0.79 to 1.08%) occurred at station S1 at the mouth of the Fly River; levels increased only slightly at most other stations over the same period.

Amounts of calcium carbonate were low (around 1.0%) at the mouth of the Fly River, medium (up to 40%) at one station near the mouth of the Fly River (S15) and at stations along the Papua New Guinea coastline (S8, S10-13), and high (> 50.0%) at all other stations.

Trace Metals and Other Elements in Sediments

Trace metal levels in pre-monsoon and monsoon sediments are summarised in appendices 4 and 5.

Spatial Patterns

CDA on all trace metals in both seasons revealed two canonical variates which explained 64.54% and 20.11% of the variation respectively (figure 1.3). Four groups of stations are apparent in the reduced plot in figure 1.3:

- Group 1: a group to the far left of the reduced plot consisting of station S1 (the station closest to the mouth of the Fly River) in both pre-monsoon and monsoon seasons
- Group 2: a large group around the centre of the reduced plot consisting of the stations S6, S8, S10, S11, S12, S13, S15 in both pre-monsoon and monsoon seasons, and station S18 in the pre-monsoon only
- Group 3: a group to the right of the focus of the reduced plot comprising stations S5, S7, S14, S16 and S17 in the pre-monsoon season, and S18 in the monsoon season
- Group 4: a group consisting of the same stations (except for S18) in the monsoon season, located at the bottom of the reduced plot

Each group is comprised of stations from similar locations in the Torres Strait (see figure 1.1). Group 1 (station S1) is the closest of all stations to the mouth of the Fly River. Group 2 consists of stations in the northern Torres Strait just south of S1 (S6 and S15), the north-central Torres Strait (S18), and stations along the coastline of Papua New Guinea (S8, S10, S11, S12, S13). Groups 3 and 4 consists of stations in the central Torres Strait (S5), Great North-East Channel (S16 and S17), and the reefs to the east of the Torres Strait (S7 and S14).

Graphs of the structural and canonical coefficients (figure 1.4) show little consistency in metals possibly influencing the arrangement of groups in the reduced plot. Consequently, the patterns in the reduced plot will be explained by reference to plots of each metal at each station (appendix 5) and results of ANOVA (appendix 6).

Stations in Groups 3 and 4 (i.e. stations in the central Torres Strait and eastern reefs: S5, S7, S14, S16, S17 in appendix 5) have low levels of the following metals and other elements, compared with other stations in the Torres Strait: aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. These stations also have higher levels of the following metals and other elements, compared with other stations: cadmium, magnesium and also calcium. There is little difference between these stations and all other stations in their levels of selenium.

Stations in Groups 1 and 2, which includes stations at the mouth of the Fly River, the northern Torres Strait and coastal Papua New Guinea (i.e. S1, S6, S8, S10, S11, S12, S13, S15 in appendix 5) have higher levels of the following metals and other elements: aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc.

In particular, Station S1 at the mouth of the Fly River has higher levels of the following metals and other elements, compared with Group 2 (coastal and northern Torres Strait) stations: aluminium, copper, nickel, silicon and zinc.

ANOVA of individual metals and other elements in both seasons (appendix 6) revealed that levels of all metals differed significantly amongst stations. Differences amongst stations explained the greatest amount of variation in the levels of all metals and other elements (see % of total variance in appendix 6), except for selenium. The amount of variation explained by differences amongst stations varied from 41.84% for mercury, to 95.56% for calcium. Differences amongst stations accounted for only 18.82% of the variation in selenium levels.

Comparison of the mean levels of metals and other elements among stations revealed the following trends (appendices 5 and 6):

- *aluminium*: in both pre-monsoon and monsoon seasons mouth of the Fly River>PNG coastal stations and northern Torres Strait stations>stations in the central Torres Strait and eastern reefs;
- *arsenic*: in both pre-monsoon and monsoon seasons PNG coastal stations and northern Torres Strait stations>mouth of the Fly River, central Torres Strait and eastern reefs;
- *calcium*: in both pre-monsoon and monsoon seasons stations in the eastern reefs and central Torres Strait> northern Torres Strait stations> PNG coastal stations>mouth of the Fly River;
- *cadmium*: in both the pre-monsoon and monsoon seasons stations in the eastern reefs> PNG coastal stations> northern and central Torres Strait stations>mouth of the Fly River;
- *cobalt*: in both the pre-monsoon and monsoon seasons mouth of the Fly River, PNG coastal stations, and northern Torres Strait stations>central Torres Strait and eastern reefs;
- *chromium*: in both pre-monsoon and monsoon seasons PNG coastal stations, mouth of the Fly River, northern Torres Strait stations>central Torres Strait stations> eastern reefs;
- *copper*: in the pre-monsoon season mouth of the Fly River>PNG coast, northern Torres Strait>central Torres Strait and eastern reefs; in the monsoon season mouth of the Fly River>all other stations;
- *iron*: in both the pre-monsoon and monsoon seasons PNG coastal stations, mouth of the Fly River, northern Torres Strait stations>central Torres Strait stations> eastern reefs;
- *mercury*: in the pre-monsoon season mouth of the Fly River>PNG coastal stations, northern Torres Strait, central Torres Strait and eastern reefs; in the monsoon season mouth of the Fly River, PNG coastal stations, and northern Torres Strait>central Torres Strait>eastern reefs;
- *magnesium*: in both the pre-monsoon and monsoon seasons central Torres Strait, eastern reefs, and northern Torres Strait>PNG coastal stations>mouth of the Fly River;

- *manganese*: in both the pre-monsoon and monsoon seasons PNG coastal stations, northern Torres Strait, mouth of the Fly River>central Torres Strait and eastern reefs;
- *nickel*: in the pre-monsoon season mouth of the Fly River>PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs; in the monsoon season mouth of the Fly River, PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs;
- *lead*: in both the pre-monsoon and monsoon seasons PNG coastal stations, northern Torres Strait, mouth of the Fly River>central Torres Strait and eastern reefs;
- *selenium*: little variation amongst all stations in both seasons;
- *silicon*: in both the pre-monsoon and monsoon seasons mouth of the Fly River>PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs;
- *zinc*: in both the pre-monsoon and monsoon seasons mouth of the Fly River>PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs.

ANOVA also revealed that the levels of some metals and other elements varied amongst sites within stations (appendix 6). These metals included: aluminium, arsenic, calcium, cadmium, cobalt, chromium, iron, mercury, magnesium, manganese, selenium, silicon and zinc. However, even though these F ratios were significant in the ANOVA, site-related variation accounted for a very small amount of the total variation (from 0 to 5.61%, with 15.04% for manganese), and was also considerably less than variation related to station differences. There were no site-related significant differences in levels of copper, nickel and lead.

In summary, this examination of spatial patterns in the levels of trace metals and other elements in the Torres Strait revealed a suite of metals and one element which are probably derived from terrigenous sources in Papua New Guinea (because their concentrations are highest at the mouth of the Fly River, the northern Torres Strait and coastal Papua New Guinea stations). These were aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. Concentrations of a number of these (aluminium, copper, mercury, nickel, silicon and zinc) were consistently higher at the mouth of the Fly River. Metals and other elements which are probably derived from marine sources (because their concentrations were consistently higher at stations in the eastern reefs and central Torres Strait) include calcium, cadmium and magnesium. Levels of selenium were similar throughout the Torres Strait.

Seasonal Patterns

The group of stations consisting of those from the eastern reefs and central Torres Strait shifted their location on the CDA reduced plot between the pre-monsoon and monsoon seasons (figure 1.3). Plots of canonical and structural coefficients do not reveal any obvious basis for this (figure 1.3). However, examination of the plots for each metal at each station (appendix 5) revealed the following seasonal differences between the groups of stations: cobalt and magnesium levels decreased at eastern reefs and central Torres Strait stations from the pre-monsoon to monsoon seasons, whereas they increased at other stations over the same time; nickel levels at eastern reefs and central Torres Strait stations increased from the pre-monsoon to monsoon season, whereas they changed little at other stations.

There were complex patterns in the variations of trace metals and other elements between seasons (appendices 5 and 6). In summary:

Metals and other elements which changed significantly between seasons at all stations
- aluminium and zinc increased in the monsoon season;
- arsenic, selenium and silicon were higher in the pre-monsoon season

Metals which changed significantly between seasons but not at all stations

- cobalt levels increased from the pre-monsoon to monsoon season at stations at the mouth of the Fly River, coastal Papua New Guinea and northern Torres Strait; levels decreased over the same period at stations in the central Torres Strait and eastern reefs;
- chromium levels increased between the pre-monsoon and monsoon seasons at all stations except S12 (coastal Papua New Guinea);
- mercury levels decreased between the pre-monsoon and monsoon seasons at all stations except S8 (coastal Papua New Guinea);
- nickel levels decreased between the pre-monsoon and monsoon seasons at all central Torres Strait and eastern reefs stations, but varied little at all other stations;
- lead levels increased from the pre-monsoon to monsoon season at all stations except S12 (coastal Papua New Guinea).

Metals which did not change between seasons

- iron levels did not change between pre-monsoon and monsoon seasons.

Metals and other elements which did not change between seasons, but not at all stations

- calcium levels were similar between pre-monsoon and monsoon seasons except at stations S12 and S8 (coastal Papua New Guinea) and S6 (northern Torres Strait);
- cadmium levels were similar between pre-monsoon and monsoon seasons except at stations in the eastern reefs (S7 and S14) where they decreased from pre-monsoon to monsoon;
- copper levels were similar between pre-monsoon and monsoon seasons except at the mouth of the Fly River (S1) where they were higher in the monsoon season;
- manganese levels were similar between pre-monsoon and monsoon seasons except at a coastal Papua New Guinea station (S8) where they were significantly less in the monsoon season.

Seasonal changes in metals and other elements were independent of their source (i.e. whether terrigenous or marine). Levels of terrigenous metals and elements either increased from the pre-monsoon to monsoon season (aluminium, zinc, cobalt, chromium, lead); or decreased over the same period (arsenic, silicon, mercury, nickel); or remained the same (iron, copper, manganese). Marine metals and other elements were similarly variable: cadmium levels increased between pre-monsoon and monsoon seasons at eastern reef stations but were unchanged at other stations; magnesium levels decreased between pre-monsoon and monsoon seasons in the central Torres Strait and eastern reefs, but increased at all other stations; calcium levels remained the same at all stations except northern Torres Strait and coastal Papua New Guinea. Selenium, not associated with any particular sediment type, decreased throughout the Torres Strait between the pre-monsoon and monsoon.

In summary, levels of most metals and other elements in sediments changed between seasons. The patterns of change across seasons and among stations was independent of both the location of stations and the source of the metals and elements.

DISCUSSION

The Extent of Influence of the Fly River into Torres Strait

A wedge of lower salinity surface water originating from the Fly River was found to extend into the Great North-East Channel during the pre-monsoon and monsoon seasons as far southward as sediment station S17, approximately half way into the Torres Strait (confirming the patterns reported by Wolanski et al 1984). During the monsoon season, when the prevailing winds are from the north-west (Dight and Gladstone 1993) the surface salinities were similar on both sides of the Warrior Reefs. This suggests either that surface water penetrate the Warrior

Reefs during the monsoon season, or alternatively, it points to the existence of a secondary source for lower salinity water into the central Torres Strait along the Papua New Guinea coastline. The latter has been hypothesised by other authors (see review by Wolanski 1991 and sediment results in Dight and Gladstone 1993).

Wolanski et al (1984) suggested that this wedge of lower salinity surface water entering the Torres Strait from the Fly River '... is probably a nearly permanent feature...' (p. 296), but representing only a small percentage of the total outflow of the Fly River. Recent work by Wolanski and others (Wolanski et al 1992a, 1992b, 1992c, 1992d) has suggested that the extent of penetration of Fly River water into the Torres Strait varies seasonally, under the influence of prevailing wind directions. Lower salinity surface water was found to penetrate further during the monsoon season, than during the trade wind season. The results of the present study differ from this pattern: surface water salinity at comparable locations at the mouth of the Fly River and in the Great North-East Channel during the pre-monsoon season was less than during the monsoon season.

Results from this study suggested that lower salinity surface water from the Fly River enters the Great North-East Channel and does not penetrate the reefs in the eastern Torres Strait. However, anecdotal observations suggest the latter is not always true. In February 1992 a plume of brown water reached Darnley Island (approximately 67 kms from the mouth of the Fly River) and deposited large amounts of logs, nets and some canoes on the beaches (D Lui pers. comm.). These events are not common, however, and are on unknown signigicance for long-term trace metal concentrations in local sediment and biota.

The results of these salinity patterns are important for the interpretation of trace metal data in the Torres Strait for two reasons: (1) dissolved and suspended particulate metals originating from the Fly River could penetrate to the middle of the Torres Strait through the Great North-East Channel; (2) trace metal levels in areas west of the Torres Strait could be influenced by sources unrelated to the Fly River. With regards to (1) Baker et al (1990) measured suspended particulate copper levels in seawater samples collected from a range of locations in the northern and central Torres Strait. Their data showed high levels of particulate copper near the mouth of the Fly River (4.2-13.3 ppb), decreasing significantly in the Great North-East Channel (0.9-5.8 ppb). Suspended particulate copper levels were lowest west of the Warrior Reefs.

Results of the physico-chemical analysis of sediments suggest a limited penetration of the Torres Strait by Fly River sediments. Amounts of fine sediment decreased markedly away from the Fly River into the Great North-East Channel and seasonal changes in amounts of fines were only observed at one station at the mouth of the Fly River. Carbonate content was high at all stations except at the mouth of the Fly River and along the Papua New Guinea coastline. The number and spacing of samples collected in the present study is insufficient to delineate with any finer resolution the limits of the Fly River's influence. However, the results of this limited sampling (especially for the distributions of carbonate content and fine sediments) correspond with the much more extensive sampling done in the Fly River delta and throughout the central and northern Torres Strait by Harris et al (1989). Harris (1991) has suggested that only about 2% of the annual sediment discharge of the Fly River enters the Torres Strait and that, based on the distributions of terrigenous mud, carbonates and copper and zinc levels (Harris et al 1989), little of this is deposited south of Bramble Cay (S15 in figure 1.1). The suggestion of other sources of terrigenous trace metals into the north-central Torres Strait from rivers along the Papua New Guinea coastline is supported by the distribution of fine sediments and organic carbon in these areas.

Distributions, Concentrations and Sources of Trace Metals and Other Elements in Torres Strait Sediments

Multivariate analysis of trace metal data revealed four clusters of stations. Each cluster was composed of sediment stations from similar locations in the Torres Strait. Station S1 at the mouth of the Fly River was a distinct group. Stations in the northern Torres Strait and along coastal Papua New Guinea formed a distinct group. Stations in central Torres Strait, Great North-East Channel and eastern reefs formed a third distinct group.

The station at the mouth of the Fly River had high levels of the same suite of metals and elements but in addition the levels there of aluminium, copper, mercury, nickel, silicon and zinc were much higher. Sediments there also have the highest proportion of fine material and organic carbon, and the lowest proportions of calcium carbonate. The group of stations in the northern Torres Strait and coastal Papua New Guinea had higher levels of aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. Sediments from these stations had a significant proportion of fine material and organic carbon, and lower content of calcium carbonate. By comparison, sediments from stations in the central Torres Strait, Great North-East Channel and eastern reefs had higher levels of calcium, cadmium and magnesium, and low proportions of fine material and organic carbon, and a high calcium carbonate content. Only one metal, selenium, occurred in similar concentrations throughout the Torres Strait.

The distribution and concentration of these metals in the Torres Strait suggests that the Fly River and smaller coastal rivers along the Papua New Guinea coastline are sources of a distinct suite of trace metals and other elements for the northern Torres Strait. These metals are: aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. Differences in concentrations of some of these metals between the station at the mouth of the Fly River and others along the coastline suggests that some metals are in higher concentrations in sediment coming from the Fly River compared with smaller coastal rivers. These metals are: aluminium, copper, mercury, nickel, silicon and zinc.

The conclusions drawn here, about the sources of trace metals in Torres Strait sediments, were based on analysis of whole sediment samples. Trace metals in sediments are mostly bound within the smaller particle size fractions. There was considerable variation in the grain size composition of sediments collected from the different stations throughout the Torres Strait. Accordingly, a more thorough understanding of the sources and spatial variations of trace metals in the Torres Strait will require additional statistical analysis which accounts for variation in grain size among stations.

In general, these trends agree with those reported in the Pilot Study (Dight and Gladstone 1993). Unlike the results reported here, the Pilot Study found that mercury and arsenic (in addition to selenium) were not associated with any particular sediment type. Mercury levels in the Pilot Study did not differ significantly amongst sampling stations; in the present study, however, mercury levels were consistently higher at Fly River and coastal stations. In retrospect, the conclusion of the Pilot Study that arsenic is not associated with any particular sediment type is surprising, given that levels were highest close to the Papua New Guinea coastline.

The geographic extent of Papua New Guinea coastal influences on Torres Strait trace metals can be estimated by examination of the levels of particular metals and their seasonal changes. Cobalt, magnesium and nickel levels in the northern Torres Strait stations S6 (at the northern end of the Great North-East Channel) and S15 (near Bramble Cay) were all less than station S1 at the mouth of Fly River, and higher than levels at stations further south in the Great North-

East Channel (S16 and S17) and the eastern reefs (S14). Seasonal changes in these metals at stations S6 and S15 followed the same pattern as Stations S1; this seasonal change was different from that which occurred at stations further south (S14, S16, S17). Similarly, levels of the same metals at station S18 in the north-central Torres Strait were slightly less than levels at coastal stations, and higher than levels at a central Torres Strait station further south (S5). Seasonal changes in these metals at S8 were the same as those occurring at coastal stations, and different from those occurring further south at S5.

This suggests that Fly River sediments and their characteristic suite of trace metals extend southward into the Torres Strait to a line between stations S6 (latitude 9°12'S) and S15 (latitude 9°08'S). Further southward sediments become more marine in their physical characteristics and their trace metal and element content. The influence of other Papua New Guinea coastal rivers on the trace metal content of sediments in the central Torres Strait, west of the Warrior Reefs, possibly extends southward as far as station S18 (9°35'S, 142°47'E).

Comparisons with Other Studies of Torres Strait Sediments

There are no consistent differences between the Main and Pilot Studies in metal concentrations at the same stations. Copper levels at S1 at the mouth of the Fly River in the Main Study during the pre-monsoon (mean = 17.89 mg/kg, SD = 2.472) were less than levels recorded at the same station and season during the Pilot Study (mean = 21.6 mg/kg, SD = 8.2); however Main Study monsoon levels (mean = 23.11 mg/kg, SD = 3.100) were greater than Pilot Study post-monsoon levels (mean = 16.7 mg/kg, SD = 1.4). Copper levels at S6 during the Main Study pre-monsoon (mean = 6.44 mg/kg, SD = 0.882) and monsoon seasons (mean = 6.78 mg/kg, SD = 1.202) were less than those reported for the Pilot Study in both the pre-monsoon (mean = 7.8 mg/kg, SD = 1.2) and post-monsoon seasons (mean = 7.2 mg/kg, SD = 0.8).

As proposed in the previous section of this Discussion, the trace metal characteristics of station S6 appear to be influenced by Fly River outflow. Estimates of copper levels at S6 were less variable than those for S1. The greater variability of estimates for S1 will affect the ability of future monitoring programs to unambiguously detect any trends in trace metal levels at this station in the short term. Decisions about changes should therefore consider changes in levels at all stations likely to be influenced by the Fly River.

Sediment copper concentrations in the Torres Strait and at the mouth of the Fly River determined in this study are similar to concentrations reported in previous studies. Copper concentrations at S1 (17.89-23.11 mg/kg) are within the range of values reported for nearshore Gulf of Papua stations (7-24 ppm) by Robertson and Alongi (1991). Copper concentrations in the < 2 mm sediment fraction reported in the present study are less than those determined by Ok Tedi Mining Ltd (reported by Waite and Szymzcak 1991) at similar locations for the < 100 μm fraction. S1 copper concentrations (17.89-23.11 mg/kg) were less than those found by Ok Tedi Mining Ltd at nearby Parama Island (35 μg/g); they were also less at S10 (7.67-8.78 mg/kg) compared with two nearby locations at Gimini Reef (10-16 μg/g; 16 μg/g).

Copper concentrations determined by Schneider (1990) for complete sediment samples are similar to results from the present study for stations in the northern Torres Strait and central Great North-East Channel. Copper concentrations found in the present study for the stations closest to the mouth of the Fly River and the most southern sites, are slightly higher than those reported by Schneider (1990). Baker and Harris (1991) reported concentrations of copper (28 μg/g), lead (13 μg/g) and zinc (91 μg/g) for sediments from the Fly River delta which were similar to values reported for the same metals at a similar location (S1) in the present study (17.89-23.11 mg/kg, 14.78-19.78 mg/kg, and 94.56-94.78 mg/kg respectively). Concentrations of copper (8.2 μg/g), lead (2.8 μg/g) and zinc (23 μg/g) in the Torres Strait reported by Baker and Harris (1991) are similar to the range of concentrations for the same metals found in the present study (2.67-12.50 mg/kg, 4.44-21.0 mg/kg, and 7.56-59.70 mg/kg respectively).

Comparisons with Studies from Other Regions

Robertson and Alongi (1991) reported that copper concentrations in the nearshore Gulf of Papua were similar to concentrations in other tropical coastal habitats and concluded that these levels were 'not abnormally high' (p 248); results from the present study are within the range of values reported by Robertson and Alongi (1991). Levels of cadmium, copper, lead and zinc in Torres Strait sediments are similar to levels found in clean offshore areas in the tropics (Peerzada and Rohoza 1989; Brady et al 1994; Reichelt and Jones 1994) and less than areas regarded as contaminated (Peerzada and Rohoza 1989; Subrananian et al 1989; Gonzalez and Torres 1990; Brady et al 1994; Reichelt and Jones 1994). Levels of copper at station S1 near the mouth of the Fly River (17.89-23.11 mg/kg) overlap with copper levels from a contaminated site in Darwin Harbour (15.7-32.2 µg/g; Peerzada and Rohoza 1989); however the latter site does not have a significant riverine influence. Levels of copper at S1 are less than levels recorded at contaminated sites in Townsville harbour (Reichelt and Jones 1994), Cuba (Gonzalez and Torres 1990) and various locations in Indian estuaries and the Bay of Bengal (Subrananian et al 1989). The highest concentrations of cadmium recorded in the present study (0.08 mg/kg at S7 and 0.05 mg/kg at S11) are less than the range of values considered to be 'normal' for 'cleaner inshore areas' (GESAMP 1985, p 12).

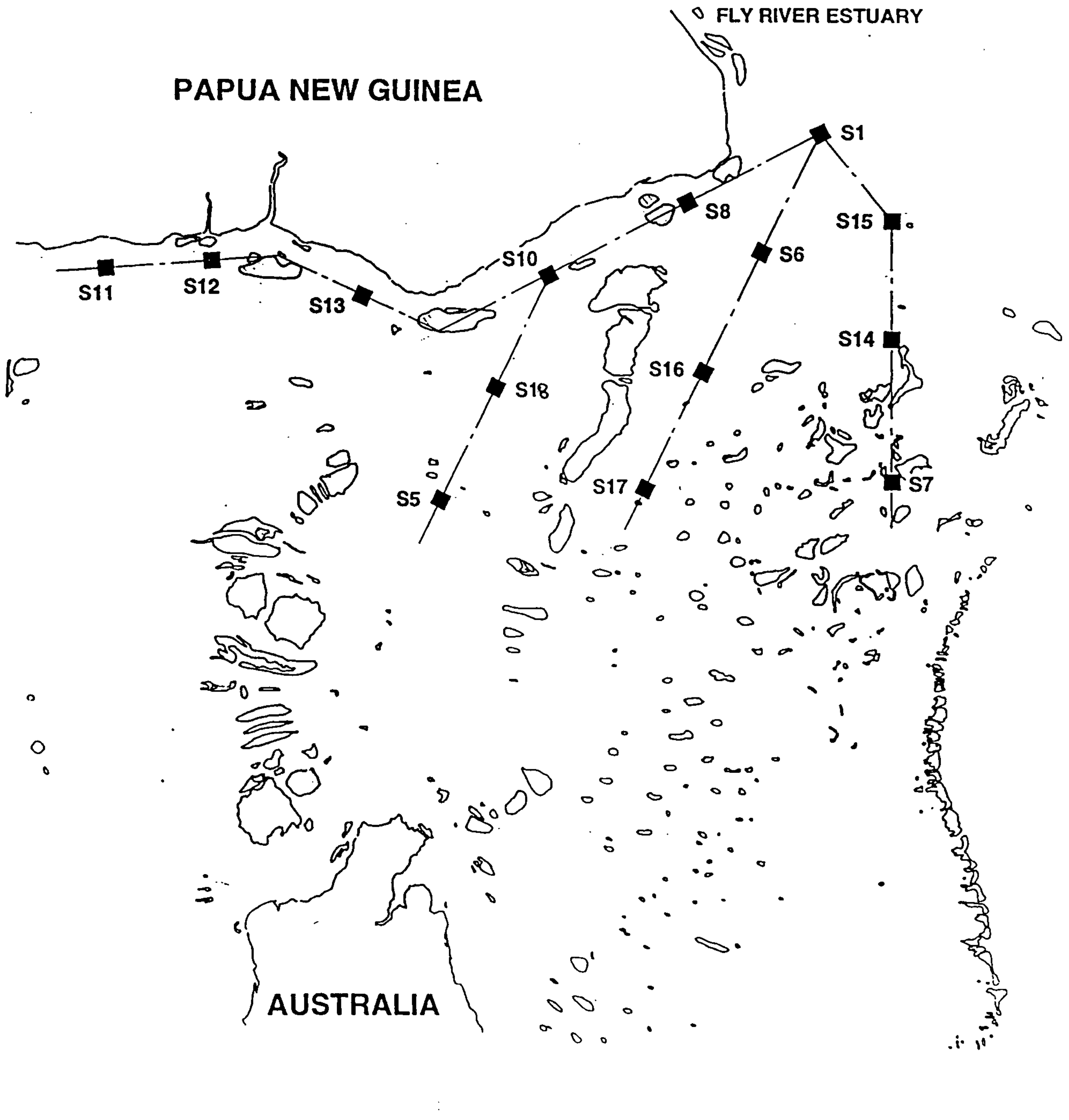


Figure 1.1. Locations of sediment collecting stations in the Torres Strait

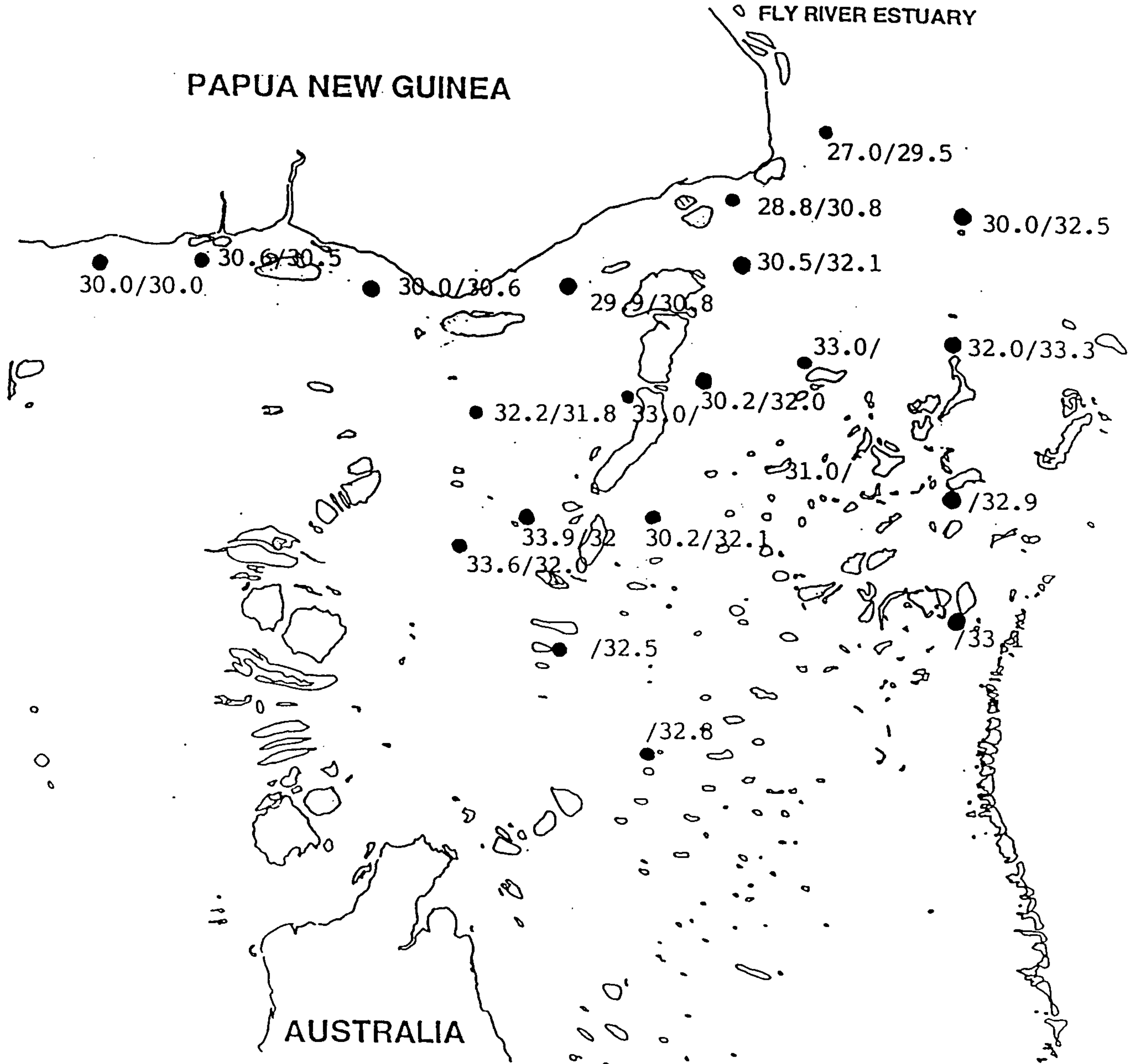


Figure 1.2. Surface salinities (in parts per thousand) in the Torres Strait during the pre-monsoon (October-November 1992) and monsoon (March 1993) seasons. The first value is the pre-monsoon salinity, the second is the monsoon salinity.

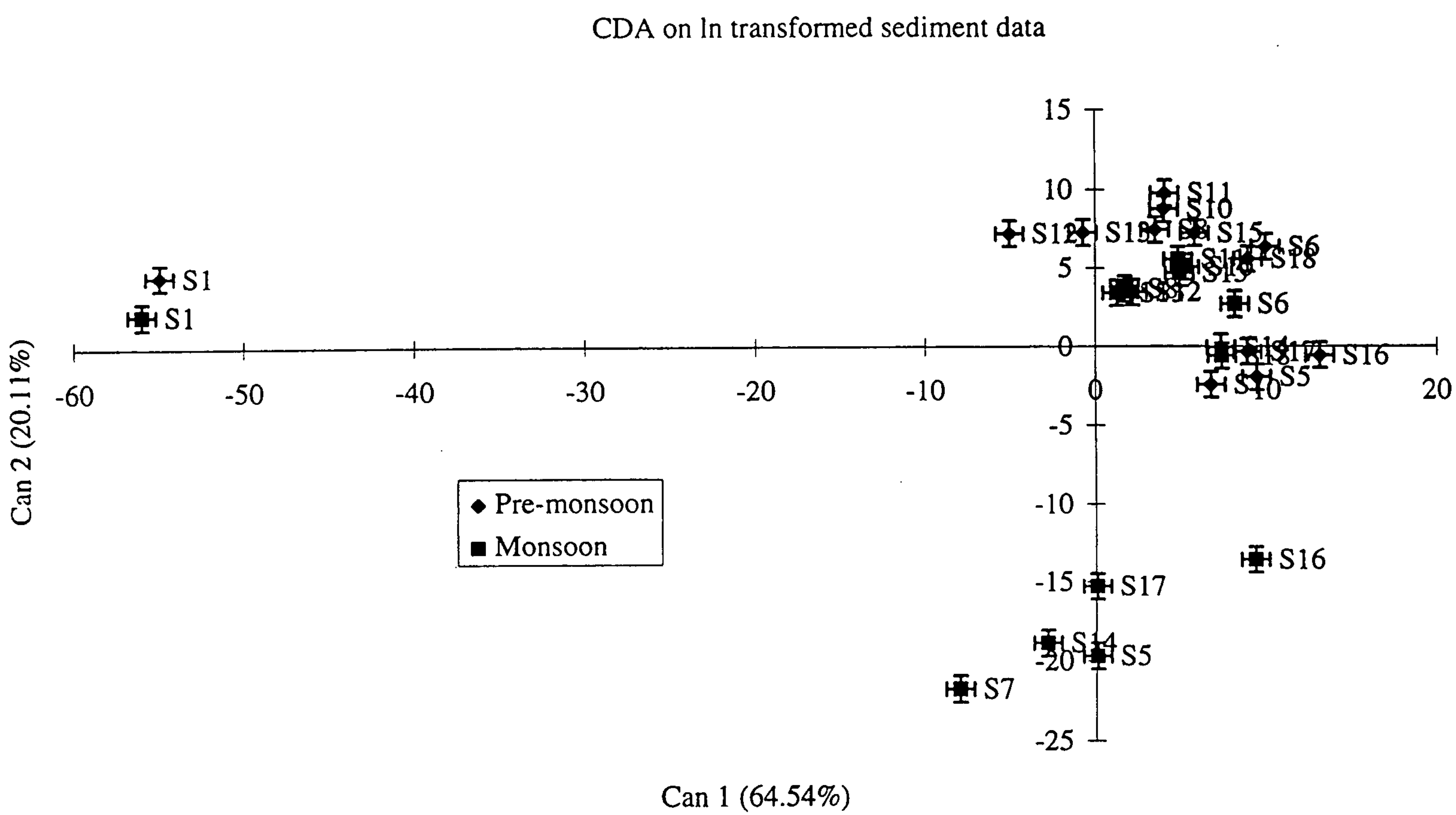


Figure 1.3. Canonical discriminant analysis (CDA) reduced plot, based on trace metal concentrations in Torres Strait sediments in pre-monsoon and monsoon seasons. The cluster of stations above the focus of the two axes contains the following stations: S6, S8, S10, S11, S12, S13, S15 in both pre-monsoon and monsoon seasons, and S18 in the pre-monsoon only. Bars around each station are 95% confidence intervals.

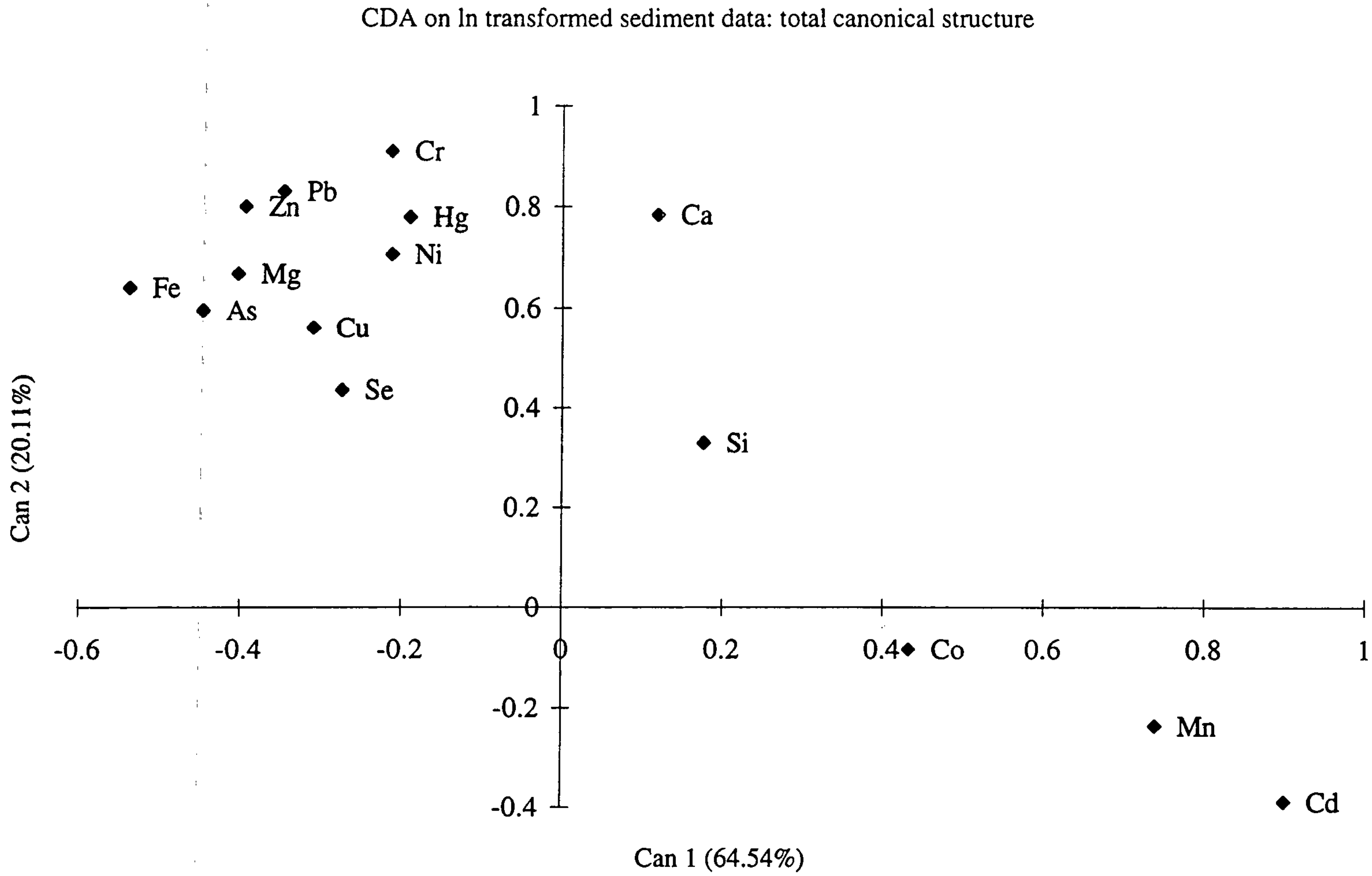
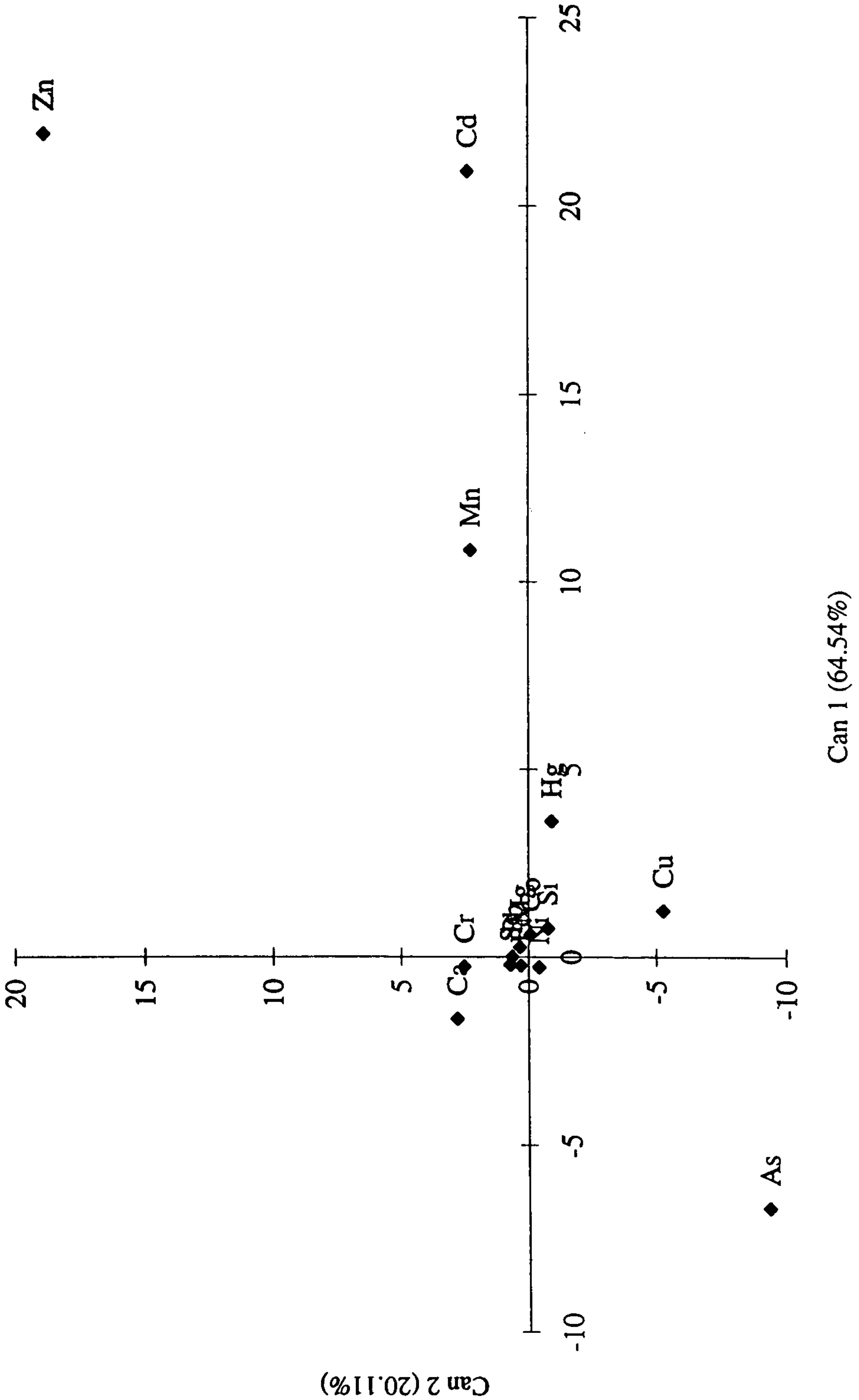


Figure 1.4. Plots of structural coefficients (this page) and canonical coefficients (following page) as a basis for explaining the patterns shown in the reduced plot (figure 1.3).

CDA on ln transformed sediment data: raw canonical coefficients



2. TRACE METALS IN INDICATOR ORGANISMS (*Tridacna crocea* and *Polymesoda erosa*)

BACKGROUND

The objectives of the biota program of the Pilot Study of the Torres Strait Baseline Study (TSBS) were to (1) investigate a number of potential indicator organisms, and recommend species for use in the Main Study; and (2) develop a preliminary analysis of the distribution of trace metals throughout the Torres Strait and their source(s).

The results from a number of organisms indicated complex spatial and seasonal patterns in the levels of many trace metals. There was little seasonal variation in the levels of most metals at locations in the central Torres Strait; however, at more northerly locations the levels of many metals were elevated in the post-monsoon season, probably under the influence of coastal runoff from Papua New Guinea (Dight and Gladstone 1993). Cadmium levels in Torres Strait biota were consistently greater than those found in the same species from the Great Barrier Reef, while copper levels were elevated at the most northern locations during the post-monsoon season.

The Pilot Study recommended two species as being particularly suitable as indicators of variations in trace metal levels throughout the Torres Strait marine environment. These species were the burrowing clam (*Tridacna crocea*) and the mangrove cockle (*Polymesoda erosa*). The Pilot Study also recommended an expanded sampling program for these indicators, including sampling during the monsoon season, rather than the post-monsoon season.

The principal objectives of the Main Study were to use the indicator organisms and sampling strategies recommended in the Pilot Study to:

(1) assess the levels of trace metals over a much greater area of the Torres Strait, and thereby to;
(2) identify the area of influence of the Fly River in the Torres Strait;
(3) provide a data set of trace metal levels in the Torres Strait which can be used as a baseline for comparison in future monitoring programs; and
(4) where necessary, suggest modifications to the sampling strategy in the light of the results gathered during the Main Study.

The results of these objectives will be reported in this chapter.

METHODS AND MATERIALS

Pre-Collecting Preparations

Prior to field trips all lab and field collecting equipment, and storage vials, were washed in 10% nitric acid, rinsed in Reverse Osmosis Polished (ROP) water and stored in clean plastic bags until used. The metal content of a sub-sample of the bags which were to be used for sample storage was determined and found to be low for all metals.

Sample Collection

Burrowing clams (Tridacna crocea)

Samples of the burrowing clam (*T. crocea*) were collected from the twelve stations shown in figure 2.1 during the pre-monsoon (October-November 1992) and monsoon (February-March

1993) seasons. At each station five replicate clams, between 70 and 80 mm shell width, were randomly collected from each of eight randomly chosen sites (i.e. a total of 40 clams per station).

Clams were collected by divers chiselling them from the coral rock. Clams damaged during collecting were discarded, to avoid possible contamination from the metal collecting tools. Collected clams were immediately scrubbed with a nylon brush, in fresh seawater in a bucket aboard the dinghy, to remove any surface adhering material from the shells which might have become contaminated during collecting. The scrubbed clams were measured, double bagged, labelled, then stored on ice for transfer back to the research vessel. Nylon brushes, buckets and measuring callipers were rinsed in fresh seawater between collecting sites, and at the end of each day were washed in ROP water.

The preparation of clam tissues for chemical analysis differed between the pre-monsoon and the monsoon collecting trips. During the pre-monsoon trip batches of refrigerated clams were air-freighted back to Horn Island at intervals of approximately three days, where they were immediately dissected by staff from the Queensland Department of Primary Industries. After cracking open the shells, the kidney was dissected free of any connective tissue and all adhering fat removed. All dissections were performed in a Class 100 NATA accredited laminar flow hood, on acid washed polypropylene cutting boards using high quality stainless steel surgical instruments. Dissected kidneys were weighed, placed in polypropylene vials, then frozen for transfer to the labs in Brisbane. Between clams and at the end of every dissecting session the dissecting instruments were scrubbed clean in Extran and rinsed three times in ROP water.

Clams were dissected aboard the research vessel during the monsoon trip. After collection the clams were immediately returned to the vessel and refrigerated prior to dissection the same evening. Dissections were done in the same way as they had been done at Horn Island, but they were undertaken in portable laminar flow cabinets. Freshly dissected kidneys were stored and handled in the same way they had been at Horn Island during the previous trip, and identical instrument cleaning protocols were followed.

The comparability of these different techniques was evaluated by comparing the metal content of two groups of clams, each with five replicates, which had been collected from the same site and at the same time. One group of clams was dissected aboard the research vessel, the other group was dissected at the Horn Island laboratory at the same time under the same conditions which had been in operation during the pre-monsoon trip. This comparison was undertaken twice, for clams collected at Kokope Reef (northern Torres Strait) and clams collected at Tom Son's Bank (southern Torres Strait). Results for each station were compared separately. Differences between the two methods were evaluated by paired t-tests for each metal separately. This involves a large number of separate calculations (16 at each station) and therefore an increasing risk of Type 1 error. This was accounted for by using an adjusted alpha significance level, calculated by the Dunn-Sidak method (Day and Quinn 1988). Differences between the two methods for each metal were significant when the t-test P value was less than the adjusted alpha.

Mangrove cockles (Polymesoda erosa)

Mangrove cockles were collected from the stations shown in figure 2.1 at the same time as samples of the burrowing clams were being collected. Five replicate cockles were randomly collected by Torres Strait Islanders from each of three randomly chosen sites in each station (i.e. a total of 15 cockles per station). Adhering mud was rinsed off with clean sea water before cockles were measured, double-bagged and labelled, then stored on ice for transfer back to the laboratory on Horn Island, where they were immediately frozen. Frozen samples were transferred to Brisbane for chemical analysis. Prior to analysis whole cockle tissues were removed from the shell, the gut opened and sediment washed out. Chemical analyses were done for whole animals (muscle with attached viscera). Funding constraints limited chemical analysis to cockles collected during the pre-monsoon season only, and it is those results which will be reported here.

Trace Metal Analysis

The majority of chemical analyses were undertaken by the Animal Research Institute of the Queensland Department of Primary Industries in Brisbane (QDPI-ARI). This laboratory successfully participated in the National Oceanic and Atmospheric Administration (NOAA) Eighth Round Inter-comparison for Trace Metals in Marine Sediments and Biological Tissues. The digestion procedure used at QDPI-ARI for trace metal determination has been accredited by the National Association of Testing Authorities (NATA). Trace metal analysis was done by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for the following metals: aluminium, arsenic, cadmium, chromium, cobalt, copper, iron, manganese, mercury, nickel, lead, selenium, silver, strontium, uranium and zinc. Complete details of the analytical procedures are described in appendix 7.

Inter-Laboratory Comparison

An inter-laboratory comparison was undertaken for samples of burrowing clams. Kidney tissue samples with a freeze-dried weight of at least 0.2 g were split and analysed by ICP-MS at both QDPI-ARI and the Australian Government Analytical Laboratories (AGAL, Sydney). Kidney samples from pre-monsoon (N=42) and monsoon (N=34) collections were analysed. Pre-monsoon and monsoon results were analysed separately on a metal-by-metal basis using paired t-tests with an adjusted alpha significance level (as described above).

Statistical Analysis

A combination of descriptive exploration, univariate analysis of variance (ANOVA), multivariate analysis of variance (MANOVA), and canonical discriminant analysis (CDA) were used. ANOVA, MANOVA, and CDA were undertaken after metal concentrations had been transformed to their natural logs. Visual inspection of the normality and homogeneity of variances (Underwood 1981) indicated that these were improved after natural log transformation.

CDA was done for all metals from all stations in each season. Station trends in each season were viewed firstly on a reduced plot. The influence of each metal on the trends depicted in the reduced plots was derived from the strength of both their canonical coefficients and structural coefficients. Metals having a strong influence on trends depicted in the reduced plots have canonical and structural coefficients which are high, and located furthermost away from the focus of the axes. Metals which displayed contradictory results for the canonical and structural coefficients are regarded as being less influential on trends depicted in the reduced plots.

For the burrowing clams MANOVA was used to test the null hypothesis that there were no differences in metal levels amongst stations at both times of the year. ANOVA were subsequently done on individual metals (using an adjusted alpha significance level) to test the null hypothesis that the metal level did not vary between seasons, stations and sites within stations. F ratios and variance components were constructed using the formulae shown in appendix 10. Variance components were calculated after preliminary examination of the ANOVAs revealed that for many metals there was a significant effect of site. Although F ratios can be statistically significant for such nested factors, they can be biologically meaningless. Calculations of the total variance explained by each factor (Underwood 1981) is a useful way of checking the magnitude of these effects. Formulae used for estimating the individual variance components are outlined in appendix 10.

For the mangrove cockles clams MANOVA was used to test the null hypothesis that there were no differences in metal levels amongst stations. ANOVA was done on individual metals (using an adjusted alpha significance level) to test the null hypothesis that levels of each metal level did not vary between stations and between sites within stations. CDA was done for all metal levels from all stations using the same procedure described above for burrowing clams.

Metal levels of some samples were below detection limits. When calculating mean metal levels of a number of samples which included samples where levels were below the detection limits, a value for these samples midway between the detection limit and zero was substituted. This is in agreement with the procedures used in the Market Basket Survey (Stenhouse 1991) and the Pilot Study (Dight and Gladstone 1993).

RESULTS

Burrowing Clams (*Tridacna crocea*)

Comparison of Methods

There were no significant differences in metal levels between the two methods for any of the 16 metals tested, at either location (table 2.1). Seasonal differences in metal levels cannot therefore be accounted for by the different methods used.

Inter-laboratory Comparisons

For the majority of metals tested in both seasons, there was no significant difference between the results from the two laboratories (table 2.2). However, there were some differences: (1) in the pre-monsoon split samples results for chromium, iron, mercury, lead and selenium were significantly different; (2) in the monsoon samples cobalt, mercury, nickel and zinc were significantly different. The greatest difference between the two labs was in their estimates of selenium in pre-monsoon samples, where the QDPI-ARI estimate (mean = 61.95 mg/kg dry weight; SD = 12.006) was almost double the AGAL estimate (mean = 34.81 mg/kg dry weight; SD = 10.282). The possible causes of this difference, and the relevance for the interpretation of the data, are discussed later in this chapter in the section Variations in Trace Metals Over Time.

Levels of Trace Metals and Other Elements

Levels of trace metals and other elements in the kidney of *T. crocea* in pre-monsoon and monsoon seasons are summarised in appendices 8 and 9. Overall, there was a significant difference in metal levels amongst stations and seasons (Pillai's trace = 4.138, $F_{368,14512} = 13.755$, $P < 0.0001$).

Spatial Patterns

Reduced plots from the CDA for both pre-monsoon and monsoon seasons are shown in figure 2.2. The first and second canonical variates explained 57.35% and 19.21% respectively of the total variation. There was a clear trend in the reduced plot of canonical variates one and two for stations to clump together in both seasons along canonical variate one according to their location in the Torres Strait on a north-south axis, i.e. the greatest amount of variation (57.35%) in the total data set of trace metal levels is explained by the location of stations.

In the pre-monsoon season stations in the northern Torres Strait (Kokope and Bramble Reefs) are located at the far right of the reduced plot; stations in the central (Warrior, Rennel, Campbell, Aureed, and Dungeness Reefs) and north-eastern Torres Strait (Underdown Reef) are situated in a cloud straddling the focus of the axes; and stations in the southern (Poll Reef and Tom Son's Bank) and eastern Torres Strait (Little Mary Reef and Hibernia Passage) are located to the far left of the reduced plot. The small amount of overlap of the confidence intervals in figure 2.2 suggests that most stations are unique from all other stations. The following groups of stations are apparent: Campbell and Rennel Reefs; Underdown, Dungeness, pre-monsoon Aureed, and monsoon Aureed Reefs; pre-monsoon and monsoon Poll Reef. The remaining stations are distinct (i.e. Kokope Reef; Bramble Reef; Warrior Reef; Little Mary Reef; Tom Son's Bank; Hibernia Passage).

A similar spatial trend was apparent in monsoon samples, however, all stations (except Poll and Aureed Reefs) were located below the first canonical axis (figure 2.2). Stations were either distinct (Kokope Reef, Bramble Reef, Underdown Reef, Hibernia Passage) or fell into distinct groups (Warrior and Campbell Reefs; Rennel and Dungeness Reefs; Little Mary Reef and Tom Son's Bank).

Plots of canonical coefficients and structural coefficients (figure 2.3) suggest a basis for the geographic trends and the seasonal differences revealed by the reduced plots. Manganese, lead, nickel and zinc approximately maintained their positions in plots of both the canonical and structural coefficients and are likely to be important in explaining the trends in the reduced plots. The position of manganese, lead and zinc to the right of canonical axis 1 and nickel at the far left suggests levels of manganese, lead and zinc were high at northern stations (i.e. Kokope and Bramble Reefs) and correspondingly low at southern stations; nickel was high at southern stations (Hibernia Passage, Poll and Little Mary Reefs and Tom Son's Bank) and low at northern stations.

This is supported by the ANOVAs for metals and other elements (appendix 10) and the comparisons of means (appendix 11), and the plots for each metal and other element (appendix 9). There were significant differences among stations for each of manganese, lead, zinc, and nickel. Manganese levels were highest at Kokope Reef and lowest at Tom Son's Bank and Hibernia Passage; lead levels were highest at Kokope and Bramble Reefs and lowest at Hibernia Passage; zinc levels were much higher at Kokope and Bramble Reefs than all other reefs, and much lower at Poll Reef, Tom Son's Bank and Hibernia Passage. By contrast, nickel levels were high at the southern stations Poll Reef, Tom Son's Bank and Hibernia Passage, and lowest at the most northern stations Kokope and Bramble Reefs.

Plots of the canonical and structural coefficients suggest that metals located close to the focus of the axes, or a small distance away from it, or metals whose positions change between the two plots, have little explanatory power in relation to the patterns displayed in the reduced plots. These metals of little influence include: silver, aluminium, arsenic, cadmium, cobalt, chromium, copper, iron, mercury, strontium and uranium (figure 2.2).

ANOVA revealed that the levels of all metals varied significantly amongst stations (appendix 10); however, the amount of the total variation that was explained by differences among stations varied for each metal. Station variation was low (6.18-8.06%) for selenium, strontium, and uranium; medium (10.33-27.41%) for aluminium, arsenic, cobalt, chromium, copper, iron, mercury and lead; and high (31.97-78.67%) for silver, cadmium, manganese, nickel and zinc. Differences among stations accounted for the greatest amount of variation (78.67% of total variation) in zinc levels.

Patterns in the levels of metals and other elements among stations are difficult to distinguish (appendix 11) because of the large degree of overlap in similarity of means. The most obvious patterns are for those metals which were also identified by the CDA as being important for separating stations i.e. manganese, nickel, lead and zinc. Levels of manganese were highest at northern stations and lowest at southern stations; levels of nickel were highest at southern stations; levels of lead and zinc were highest at northern stations and lowest at southern stations. Additionally, patterns in silver levels were also clear: silver was highest at one of the most northern stations (Kokope Reef).

The following trends are apparent in the remaining metals and other elements:

- *aluminium*: highest at southern (Poll Reef) and northern (Kokope Reef) stations in the pre-monsoon; highest at a northern (Bramble Reef) and eastern (Little Mary Reef) station in the monsoon season;
- *arsenic*: highest at central (Dungeness Reef) and northern (Kokope Reef) stations in the pre-monsoon; highest at two central stations (Warrior and Dungeness Reefs) in the monsoon season;
- *cadmium*: highest at northern (Kokope Reef) and central (Warrior Reef) stations in the pre-monsoon; lowest at a south-eastern station (Hibernia Passage) in the monsoon season;
- *cobalt*: highest at two central stations in the pre-monsoon (Dungeness and Rennel Reefs); highest at central (Dungeness Reef) and southern (Poll Reef) stations in the monsoon season;
- *chromium*: highest at south-eastern (Hibernia Passage) and central (Dungeness Reef) stations in the pre-monsoon; lowest at a northern station (Kokope Reef) in the monsoon season;
- *copper*: highest at the most northern stations (Bramble and Kokope Reefs) in both pre-monsoon and monsoon seasons;
- *iron*: highest at central (Dungeness Reef) and northern (Kokope Reef) stations in the pre-monsoon; highest at two central stations (Dungeness and Warrior Reefs) in the monsoon season
- *mercury*: highest at northern and central stations in both the pre-monsoon (Bramble and Aureed Reefs) and monsoon (Bramble and Rennel Reefs) seasons;
- *selenium*: highest at eastern (Little Mary Reef) and south-eastern (Hibernia Passage) stations in the pre-monsoon; highest at central (Aureed Reef) and southern stations (Poll Reef) in the monsoon season;
- *strontium*: highest at central stations (Warrior and Campbell Reefs) in the pre-monsoon; highest at central (Warrior Reef) and southern (Poll Reef) stations in the monsoon season;
- *uranium*: highest at eastern and central stations in the pre-monsoon (Little Mary and Dungeness Reefs) and the monsoon (Aureed and Little Mary Reefs).

In addition to significant station effects, almost half the metals and other elements analysed displayed statistically significant site effects (appendix 10). These included: silver, aluminium, chromium, iron, manganese, lead, selenium, uranium and zinc. In almost all cases, however, the amount of variation explained by differences amongst sites was small (2.23-7.92%) relative to variation amongst stations. The exception to this was uranium where the amount of total variation explained by variation among sites (7.48%) was similar to the amount explained by variation among stations (8.06%).

There were no significant site effects for arsenic, cadmium, cobalt, copper, mercury, nickel and strontium.

Seasonal Patterns

The reduced plot revealed a distinct spatial arrangement of stations, which was consistent between seasons. The arrangement of stations, however, was shifted below the first canonical axis in the monsoon season (figure 2.2). The only exceptions to this were Poll and Aureed

Reefs. Examination of the canonical and structural coefficients shows that selenium has a high value for both on the second canonical axis, suggesting that the shift in location between seasons was due to changes in selenium levels between the two seasons. Selenium levels dropped across all stations between the pre-monsoon and monsoon seasons (appendix 9), and this appears to be the greatest drop by any metal over the two seasons. The drops in levels of selenium were least at Poll and Aureed Reefs.

ANOVA (appendix 10) revealed that levels of the following metals and other elements differed significantly between the pre-monsoon and monsoon seasons: aluminium, cobalt, copper, iron, mercury, nickel, lead, selenium, strontium, uranium, and zinc. The amount of total variation that was explained by seasonal variations was low (1.20-8.83%) for aluminium, mercury, manganese, nickel, lead and zinc; medium (10.24-19.55%) for cobalt, copper, iron, strontium, and uranium and high (60.22%) for selenium.

For some metals and other elements with a significant seasonal difference, there was also a significant interaction effect (season X station; appendix 10). These were: aluminium, mercury, manganese, lead, and selenium. Examination of station and seasonal means for each of these (appendix 9) suggests that they varied seasonally in the following ways:

- *aluminium* (Al): pre-monsoon levels exceeded monsoon levels at all stations except at Bramble Reef and Little Mary Reefs where monsoon levels exceeded pre-monsoon levels;
- *mercury* (Hg): pre-monsoon levels less than monsoon levels at all stations except Aureed, Underdown and Little Mary Reefs where pre-monsoon levels exceeded monsoon levels;
- *manganese* (Mn): pre-monsoon levels exceeded, or were equal to, monsoon levels at all stations except Dungeness Reef where pre-monsoon levels were less than monsoon levels;
- *lead* (Pb): pre-monsoon levels exceeded monsoon levels at all stations except Dungeness Reef where pre-monsoon levels were less than monsoon levels;
- *selenium* (Se): pre-monsoon levels far exceeded monsoon levels at all stations except Campbell Reef.

Metals and other elements where there was a significant difference between seasons and a non-significant interaction effect were: cobalt, copper, iron, nickel, strontium, uranium and zinc. Overall, pre-monsoon levels were higher than monsoon levels, except zinc where pre-monsoon levels were less than monsoon levels (appendix 9).

There was no significant difference in levels between seasons for the following metals: silver, arsenic, cadmium and chromium (appendix 10).

Mangrove Cockles (*Polymesoda erosa*)

Size Differences Among Stations

Mangrove cockles varied in size from 48.7 mm to 113.4 mm shell length (all stations combined). Shell length varied significantly amongst stations (appendix 12); however, the Pilot Study (Dight and Gladstone 1993) found no significant relationship between shell length and levels of any trace metals.

Spatial Patterns

Appendices 13 and 14 are summaries of the levels of trace metals and other elements in mangrove cockles. Levels differed significantly amongst all stations and amongst some sites within stations (Pillai's trace = 4.489, $F_{112,721} = 11.5102$, $P < 0.0001$).

Canonical discriminant analysis of all trace metals and other elements at all stations revealed that the first and second canonical variates explained 47.22% and 19.51% respectively of the variation in trace metal levels (figure 2.4). No geographic trends are apparent in the relative positions of stations on the reduced plot in figure 2.4. Three stations (Kussa, Boigu and Sassie Islands) are more similar to one another than they are to other stations; all other stations are distinct from each other.

Plots of the canonical and structural coefficients (figure 2.5) suggest that each station is distinct from other stations on the basis of levels of one to two trace metals. When the locations of the stations on the reduced plot are compared with the positions of metals which maintain consistent positions on plots of the canonical and structural coefficients, the following associations are revealed:

(1) stations to the right of the vertical axis (Kussa, Sassie, Boigu and Bobo Islands) have higher levels of arsenic and lower levels of manganese compared with stations to the left of the vertical axis;
(2) the cluster of stations consisting of Kussa, Sassie and Boigu Islands has higher levels of lead than other stations;
(3) Bobo Island has consistently higher levels of uranium than any other station;
(4) Saibai Island is not distinguished by any particular association(s) of metals; and
(5) each of Daru Island, Parama Island, and Warukuik Creek have higher levels of manganese than other stations.

The separation of Daru Island, Parama Island and Warukuik Creek is not apparent on the reduced plot, but is explained by the plots of the individual metal levels (appendix 14). Warukuik Creek has higher levels of uranium than either of the other two stations, and Daru has higher levels of lead than either of the other two stations.

Metals close to the focus of the axes which were not important in separating stations included: nickel, cadmium, chromium, silver, aluminium, and mercury.

ANOVA of levels of trace metal and other elements (appendix 15) revealed that levels of the following metals did not vary significantly among stations: silver, chromium, copper, nickel, and strontium.

Levels of the following metals and other elements varied significantly among stations: aluminium, arsenic, cadmium, cobalt, iron, mercury, manganese, lead, selenium, uranium, and zinc (appendix 15). Results in the previous chapter for trace metals in sediments suggests that eight of these are derived from terrigenous sources: aluminium, arsenic, cobalt, mercury, iron, manganese, lead, and zinc. Additionally, some of these metals (aluminium, cobalt, mercury, and zinc) were in higher concentrations in sediment from the Fly River compared with other coastal sources. This leads to two predictions about the relative levels of these metals between stations:

(1) levels of all these metals should be higher at stations closer to mainland Papua New Guinea. This prediction is not reflected in differences in the levels of these metals (from appendix 13) between the following pairs of stations (the first station in each pair is classified as nearshore): Kussa and Boigu Islands; Warukuik Creek and Saibai Island; Daru and Bobo Islands; Parama and Sassie Islands. At most, only half of the metals were higher at the nearshore stations, and no metal was consistently higher at the nearshore station in any of the comparisons.

(2) levels of aluminium, cobalt, mercury and zinc should be higher at stations closer to the Fly River. This is not reflected in the results for any of these metals in appendix 13. Aluminium was highest in mangrove cockles from Boigu Island; cobalt was highest at Boigu Island and

Warukuik Creek; mercury was highest at Warukuik Creek; and zinc was highest at Kussa Island. In fact, levels of all these metals were lowest, or near the lowest, at Parama Island (the station closest to the mouth of the Fly River).

There were significant differences in the levels of mercury and nickel amongst sites within a station (appendices 14 and 15). Mercury levels differed amongst sites at Warukuik Creek and Bobo Island; nickel levels differed amongst sites at Boigu Island and Daru. Examination of the raw data reveals that these are all real site differences (i.e. levels in all individuals from one site are higher than all individuals from other sites). There were no obvious sources of pollution near any of these sites.

DISCUSSION

Burrowing Clams (*Tridacna crocea*)

Variations in the Levels of Trace Metals and Other Elements Throughout the Torres Strait and Requirements for Future Monitoring

Trace metals and other elements entering the Torres Strait from mainland Papua New Guinea and the Fly River exist in particulate and dissolved forms. Intuitively, the extent of penetration of both of these forms into the Torres Strait marine environment should differ with the dissolved forms being more mobile. Results from the sediment analyses presented earlier in this report, and studies by Harris et al (1989) and Baker et al (1990), suggest that Fly River sediments and suspended particulates enter the northern Torres Strait as far as a line between Bramble Cay and Kokope Reef. The extent of penetration of the dissolved forms of metals is unknown. The kidney of the burrowing clam *T. crocea* reflects levels of the dissolved portions of trace metals in the surrounding environment (Denton 1987). An efficient and reliable sampling program for monitoring levels of trace metals in Torres Strait will be dependent on choosing the most appropriate sampling stations for detecting changes in background levels. It is therefore important to understand the spatial extent of influence of the Fly River in Torres Strait.

Multivariate analysis of all trace metals revealed a distinct arrangement of stations which corresponded to their locations in the Torres Strait on a north-south axis. The relative position of stations was largely influenced by levels of lead, manganese, nickel, and zinc. Lead, manganese and zinc levels were highest at northern stations and lowest at southern stations; nickel levels were lowest at northern stations and highest at southern stations. It is not surprising that lead, manganese and zinc levels are important in separating stations as the Pilot Study (Dight and Gladstone 1993) and sediment results in the present study identified these metals as being derived from mainland Papua New Guinea. However, nickel was also identified as a metal derived from the Fly River. Other Fly River derived metals which displayed this unexpected trend included aluminium, cobalt and chromium. High levels of these metals in both the southern and northern Torres Strait, relative to central Torres Strait stations, suggests there could be an additional source of metals which is influencing the southern Torres Strait e.g, mainland Australia. Alternatively, the uptake of these metals by *T. crocea* could be more strongly influenced by other factors varying along the same north-south gradient e.g. temperature and salinity.

There is no consistently clear relationship between the source of metals and their levels in burrowing clams at different locations in the Torres Strait. Metals which had little influence on the arrangement of stations in the CDA included some (aluminium, arsenic, cobalt, chromium, copper and iron) which have been identified in the present study as terrigenous-derived metals. Levels of some terrigenous-derived metals were highest in the southern Torres Strait (chromium and nickel); levels of others were highest in both the northern and southern Torres Strait (aluminium); levels of others were highest in the central Torres Strait (arsenic, cobalt, iron). Terrigenous metals with highest levels in the northern Torres Strait included copper, manganese, mercury, lead and zinc.

It is therefore difficult, on the basis of these conflicting trends, to distinguish clearly the geographic extent of influence of the Fly River on trace metal levels in burrowing clams. The separation of Kokope and Bramble Reefs from other stations in the Torres Strait by canonical discriminant analysis of all trace metal levels, and the higher levels of some terrigenous and Fly River metals at these stations (copper, manganese, lead and zinc) suggests they are more consistently influenced than other stations in the Torres Strait. Burrowing clams from these stations are therefore likely to reflect changes in background levels of dissolved trace metals entering the Torres Strait from the Fly River.

Future monitoring programs should therefore include, as a minium, Kokope and Bramble Reefs. A need for comparisons with stations unlikely to be influenced by the Fly River suggests that a number of stations in the central Torres Strait (e.g. Campbell, Rennel, Aureed and Poll Reefs) should also be included. Although Bramble Reef is important for future monitoring, it may be difficult in the future to collect sufficient burrowing clams from there (it was difficult to sample the recommended number of replicates during the Main Study). In that case it may be desirable to examine alternatives e.g. transplanting clams and sampling them after a specific time period.

All metals and other elements displayed significant differences in levels among stations throughout the Torres Strait. This result is quite different from the Pilot Study where levels of ten of the metals and other elements tested did not significantly vary amongst stations (aluminium, arsenic, chromium, cobalt, manganese, mercury, lead, strontium, selenium and uranium). This list includes two (manganese and lead) which varied significantly in the present study and were important in separating stations in the multivariate analysis. Metals which varied amongst stations in the Pilot Study included silver, cadmium, copper, iron, nickel and zinc. Geographic trends in the levels of these metals were consistent between the Pilot and Main Studies: silver, cadmium, copper and zinc were highest at stations in the northern Torres Strait; iron was highest in the central Torres Strait; and nickel was highest at the most southern stations in both studies. Long-term monitoring to provide a better understanding of the extent of these variations is essential for interpreting potential anthropogenic changes in the levels of any of these metals.

Variations in Trace Metals Over Time

The Pilot Study (Dight and Gladstone 1993) recommended that sampling for indicator organisms be undertaken in the monsoon season (rather than the post-monsoon). During the monsoon season in the Torres Strait the prevailing winds are from the north-west and this is believed to be the time of penetration of the Torres Strait by brackish water from the Fly River. Trace metal levels in burrowing clam kidneys sampled during the monsoon season in the northern Torres Strait should therefore reflect the levels of terrigenous trace metals in Fly River water (assuming a direct relationship between environmental levels and kidney levels). Sampling during the monsoon season should therefore provide a better indication of the levels of trace metals in Fly River water entering the Torres Strait. Sampling for the Main Study was accordingly undertaken in the monsoon months of February-March 1993. Results presented here show that levels of many metals varied between the pre-monsoon and monsoon seasons, but not in ways consistent with the above assumption In particular, levels of cobalt, copper, iron, nickel, strontium and uranium dropped between the pre-monsoon and the monsoon seasons at all stations; zinc levels at all stations increased between the pre-monsoon and monsoon seasons. Selenium dropped from the pre-monsoon to monsoon season at all stations.

Levels of aluminium, manganese, lead also dropped between the pre-monsoon and monsoon seasons but not at all stations. Mercury levels increased between the two seasons, but not at all stations. Levels of some metals (silver, arsenic, cadmium and chromium) did not change between seasons.

The trend for levels of most metals and other elements to drop between the pre-monsoon and monsoon seasons is unexpected, given that the range of metals involved includes a number (aluminium, cobalt, copper, iron, manganese, nickel and lead) believed to be coming from the Fly River. Chromium was identified as a terrigenous metal, but its levels did not change between seasons. Physical data gathered during this study which points to a greater influence of the Fly River in the monsoon season at the time of this study is equivocal: surface salinities in the northern Torres Strait during the pre-monsoon season were less than during the monsoon season; however, the proportion of fine sediment in the total sediment fraction collected from the mouth of the Fly River increased during the monsoon season.

A more complete understanding of seasonal trends in trace metal levels is difficult without information on seasonal changes in the indicator's biology, especially growth and reproduction. Increases in tissue mass, possibly associated with seasonal changes in growth and gonad development, can'dilute' (Rainbow 1988) trace metal content and obscure environmental changes. This information is not available for the burrowing clam in Torres Strait.

Seasonal changes in the levels of trace metal and other elements in burrowing clam kidneys did not, in general, reflect the seasonal changes which were recorded in the sediments (based on observation of the two data sets). Only four metals (cadmium, nickel, selenium and zinc) recorded similar changes in clam kidneys and sediments.

The seasonal changes that are reported here differ considerably from those reported in the Pilot Study (Dight and Gladstone 1993). In the Pilot Study trace metal levels were compared between pre-monsoon (October 1991) and post-monsoon (April-May 1992) seasons. The results revealed that, unlike the present results, levels of only two metals (mercury and selenium) dropped between the two seasons. Levels of many metals were greater in the post-monsoon season, including arsenic, cobalt, nickel, lead, and uranium. Levels of some other metals were also greater in the post-monsoon season but only at the most northern stations, including cadmium, copper, strontium, and zinc.

The kidney of the burrowing clam has been shown experimentally by Denton (1987) to be an excellent indicator of trace metal levels in the surrounding environment. However, their use and the interpretation of the results, must consider that the relationship between metal levels in the environment and levels in clam kidneys is complex and probably influenced by other environmental factors such as temperature, salinity, pH, as well as factors related to the indicator, such as growth and reproduction. In addition, the timing, and the magnitude, of trace metal input into the northern Torres Strait from the Fly River is probably not consistent from year to year.

The possibility that the Fly River's influence on the northern Torres Strait during the monsoon season varies spatially and temporally suggests that future monitoring should take this into account, especially for copper. Denton (1987) has shown that although kidney copper levels have an accumulation half-time of only one to three weeks, and attain equilibrium after 20 weeks, copper is lost rapidly when the environmental levels drop (its renal half-life is around seven weeks). If Fly River inputs are temporally variable it is possible that a rigid sampling program undertaken during the monsoon season will miss maximum input into the Torres Strait, and clam kidneys will thus not provide a realistic signature of Fly River trace metal levels.

The design of the present study detected a significant change in the levels of copper over time. This change corresponded to a real difference between pre-monsoon (mean of all stations = 2.92 mg/kg, SE = 0.12) and monsoon (mean of all stations = 2.37 mg/kg, SE = 0.08) of 18.8%. The ANOVA was done on natural log transformed data which corresponded to a seasonal difference of 19.5%. These values are the maximum difference that was detected so it is possible that the design could be powerful enough to detect smaller changes through time. The desired change able to be detected (and the possible implications of this for the extent and cost of a sampling program) should be considered in any future discussions on the need for long-term monitoring of trace metal levels in the Torres Strait.

Multivariate analysis of the entire trace metal data set revealed patterns among stations that were consistent between seasons. There was, however, a major shift in the location of the stations on the reduced plot that was shown to be caused by a large decrease in the levels of selenium at all stations. The Pilot Study also detected a significant drop in the level of selenium between the pre and post-monsoon seasons. The extent of the drop recorded in the Main Study was much greater than in the Pilot Study. Both studies could be reflecting a true decrease in the availability of selenium between seasons. And this is supported by the sediment results presented earlier in this report which showed a significant decrease in selenium levels in sediments throughout the Torres Strait.

Interestingly, this trend for selenium to drop in the monsoon season was only detected by one of the labs in the inter-laboratory comparison. That comparison showed that for the same kidneys, levels of selenium reported by QDPI-ARI were almost double those reported by AGAL. The reasons for these differences are unclear, considering the lack of consistent differences for any metals across seasons (except mercury) and the similarity in analytical methods used by the two labs (both used ICP-MS). One possible explanation is non-uniform storage of these metals within the kidney tissues, though this possibility does not appear to have been investigated in studies of these tissues (references in Denton 1987). A more likely explanation is differences in sample handling procedures between the two labs. The lab which reported a seasonal change in selenium was used for the majority of analyses.

Comparisons with Earlier Torres Strait Studies

Trace metal levels in *T. crocea* from the Torres Strait have been determined for samples collected between 1978 and 1985 (Denton and Heitz 1991). Results of this analysis are compared with the present results in appendix 16. For the metals tested, the range of means of the present study is either within the range of means of the earlier study (for cadmium, nickel and zinc), or less than the earlier study (copper and lead).

There was insufficient time to statistically compare the results of the Main and Pilot studies. The following trends are apparent from a comparison of results for a limited number of metals at the same sampling stations:

- *copper*: levels detected in the Main Study were less than those detected in the Pilot Study at the one of the northern-most stations (Kokope Reef) and a central Torres Strait station (Dungeness Reef); levels at two central stations (Campbell and Aureed Reefs) were similar in both studies;
- *zinc*: levels detected in the Main Study were greater than those detected in the Pilot Study at all stations except Kokope Reef where they were similar;
- *lead*: Main Study levels were greater than Pilot Study levels at all stations in the pre-monsoon season and at Dungeness Reef during the monsoon season; levels were equal at Aureed Island during the monsoon season; Main Study levels were less than Pilot Study levels at Campbell and Kokope Reefs during the monsoon season;

- *nickel*: Main Study levels were greater than Pilot Study levels at all stations during the pre-monsoon, and less during the monsoon season;
- *cadmium*: Main Study levels were greater than Pilot Study levels at all stations in the pre-monsoon and at Aureed Reef in the monsoon; Main Study levels were less than Pilot Study levels during the monsoon at Campbell and Kokope Reefs; Main Study levels were similar to Pilot Study levels at Dungeness Reef in the monsoon season.

Inter-Regional Comparisons

A large data set is available (Burdon-Jones and Denton 1984a, b) for comparing trace metal levels in *T. crocea* between the Torres Strait and the Great Barrier Reef and is summarised in appendix 17 for cadmium and copper.

Cadmium levels are consistently higher in the Torres Strait than at comparable locations on the Great Barrier Reef. For example, amongst midshelf reefs the mean cadmium level in specimens collected from Rennel Reef during March 1993 (139.38 mg/kg) was about 27 times higher than mean levels at Orpheus Island (5.09 µg/g) in January 1983.

By contrast, mean copper levels at all locations in the Torres Strait were below the levels found at comparable sites on the Great Barrier Reef (appendix 17). The only exceptions to this occurred (1) amongst Nearshore locations where mean copper levels at Bramble Reef (which is about 34 km from the mouth of the Fly River) during October 1992 (3.9 mg/kg) were about the same as levels reported from Orpheus Island during January 1983 (3.86 µg/g); and (2) amongst Midshelf locations where mean copper levels at Rennel Reef during October 1992 (2.74 mg/kg) were similar to the levels found at Lizard Island during April 1982 (2.77 µg/g). At Kokope Reef, another Nearshore location which is only about 57 km from the mouth of the Fly River, mean copper levels were all less than levels recorded at Orpheus Island. Clams sampled by Burdon-Jones and Denton (1984a, b) were large (10-12 cm shell length) compared to clams sampled for the present study (7-8 cm). Although it has been demonstrated that no relationship exists between shell length and levels of cadmium and copper (Denton and Heitz 1991; Dight and Gladstone 1993) clams sampled for the Great Barrier Reef study are probably considerably older than the Torres Strait clams.

Levels of nickel, lead and zinc can be compared by reference to appendix 8 in this report, and to tables 8.6-8.10 in Burdon-Jones and Denton (1984a) and tables 10.7, 11.7, 12.7, 13.7 and 14.7 in Burdon-Jones and Denton (1984b) (all of which are summarised as table 4 pp 54-55 in Dight and Gladstone 1993). This shows that amongst Torres Strait Nearshore, Midshelf and Offshore locations (as defined in appendix 17 of this report) levels of nickel and lead were less than at Great Barrier Reef locations, while Torres Strait zinc levels were similar to, or exceeded, Great Barrier Reef levels. It is important to point out here that inter-regional comparisons should be viewed cautiously. Inter-laboratory comparisons of results for these metals produced significantly different results between two labs, despite the use of identical technology (ICP-MS). The inter-regional comparisons reported here were based upon results obtained from different analytical techniques, which could be influencing the magnitiude of the differences.

The results of this comparison support the conclusions of the Pilot Study (Dight and Gladstone 1993) that the levels of trace metals recorded for *T. crocea* in the Torres Strait are comparable to levels which have been detected in the species from unpolluted waters. The only exception to this is cadmium, which is consistently elevated in *T. crocea* from the Torres Strait.

Mangrove Cockles (*Polymesoda erosa*)

Mangrove cockles are filter feeding molluscs inhabiting muddy areas in mangroves of islands along the Papua New Guinea coastline and throughout the central Torres Strait. They were chosen as indicator species for this study as they were believed to reflect available levels of dissolved and particulate trace metals (Dight and Gladstone 1993). Most of the stations from which mangrove cockles were collected were located close to the Fly River and mainland Papua New Guinea, the only exception being Sassie Island in the central Torres Strait (figure 2.1). A reasonable hypothesis would be that levels of trace metals at stations near the mouth of the Fly River and Missionary Passage (i.e. Bobo, Daru and Parama Islands) would be more similar to one another than to stations at other locations further along the coast where local riverine influences are probably more important (i.e. Warukuik Creek, and Saibai, Boigu and Kussa Islands).

Associations of stations revealed by the canonical discriminant analysis were unexpected. Kussa and Boigu Islands are about six kilometres apart and, not surprisingly, were very similar to one another in their levels of trace metals. They were, however, grouped together with Sassie Island on the basis of similar levels of lead, and to a lesser extent arsenic. Lead is a terrigenous-derived metal and was shown in the sediment results (appendix 6) to be in similar, but higher, concentrations at stations along the Papua New Guinea coastline, compared with central Torres Strait stations.

Conversely, Bobo and Daru Islands are less than five kilometres apart but were shown to be very different in their combinations of trace metals; Bobo Island had much higher levels of uranium and arsenic, and lower levels of manganese, than Daru Island. Other metals known to be derived from terrigenous sources (including the Fly River) were not important in separating stations, and their levels did not differ amongst stations; these metals included silver, chromium, copper and nickel. This is supported by sediment chromium levels which were similar at Fly River and coastal stations; however, levels of copper and nickel in sediments were significantly higher near the mouth of the Fly River than at coastal stations (appendix 6). The potential importance of local influences is highlighted by nickel, where variability amongst sites (within stations) was greater than variability between stations.

Patterns in the levels of trace metals in mangrove cockles suggest that the influence of the Fly River (as predicted by the oceanography, see Wolanski et al 1984) on the bioavailability of trace metals for mangrove cockles is possibly overridden by small-scale local influences, including other riverine input along the coastline.

Interpretation of these results is possibly confounded by the differences in sizes of mangrove cockles from the different stations. For example, mangrove cockles from Kussa and Boigu Islands, only 6 kms apart, had similar levels of most trace metals, although their sizes were significantly different (appendix 12). Further, there was a significant difference between the levels of trace metals in mangrove cockles from Bobo and Daru Islands (which are less than 5 kms apart), and there sizes were also significantly different. The Pilot Study (Dight and Gladstone 1993) concluded that size had no effect on levels of trace metals in mangrove cockles; however, this needs to be re-examined with the larger data set from the Main Study. Future monitoring programs should be modified so that only mangrove cockles of a similar size range are collected from the different localities.

Comparisons with Other Studies

No other studies have investigated the levels of trace metals in the mangrove cockle *P. erosa*. Comparisons are possible, however, with many studies on other filter feeding molluscs in similar tropical environments. Trace metal data for *P. erosa* throughout the Torres Strait are summarised in appendix 13. The range of mean cadmium levels (0.05-0.19 mg/kg dry weight) was less than the range reported for mussels from a range of unpolluted locations around Hong Kong (0.75-1.30 µg/g dry weight; Chan 1989). When this range of cadmium means for *P. erosa* is converted to a wet weight basis (0.011 -0.06 mg/kg) it is less than ranges reported for oysters from the Northern Territory (0.4-8.5 µg/g; Peerzada et al 1993), Arnhem Land (0.25-10.6 µg/g; Peerzada and Dickinson 1989), and Shark Bay (2.3-14.4 ppm; McCoonchie et al 1988).

Mean wet weight levels of copper in *P. erosa* from the Torres Strait (0.34-0.86 mg/kg) are less than levels recorded in oysters from comparable unpolluted locations along the Northern Territory (6.0-58.3 µg/g; Peerzada et al 1993) and Arnhem Land (5.2-58.3 µg/g; Peerzada and Dickinson 1989) coastlines. They are similar to copper levels in pearl oysters from unpolluted locations around Shark Bay (an average of 0.5 ppm; McConchie et al 1988).

Dry weight means for copper (1.93-5.37 mg/kg) in *P. erosa* are less than mean levels recorded in mussels from pristine locations near Hong Kong (17.2-28.9 µg/g; Chan 1989), and considerably less than mean levels recorded in mussels from polluted waters in Hong Kong (158.0 µg/g; Chan 1989; 8.5-278 µg/g; Phillips 1989) and oysters from polluted waters off Sydney (an average of 110 mg/kg; Scanes et al 1995).

The results of this comparison support the conclusions of the Pilot Study (Dight and Gladstone 1993) that the levels of trace metals recorded for *P. erosa* in the Torres Strait are comparable to levels which have been detected in similar species from unpolluted waters.

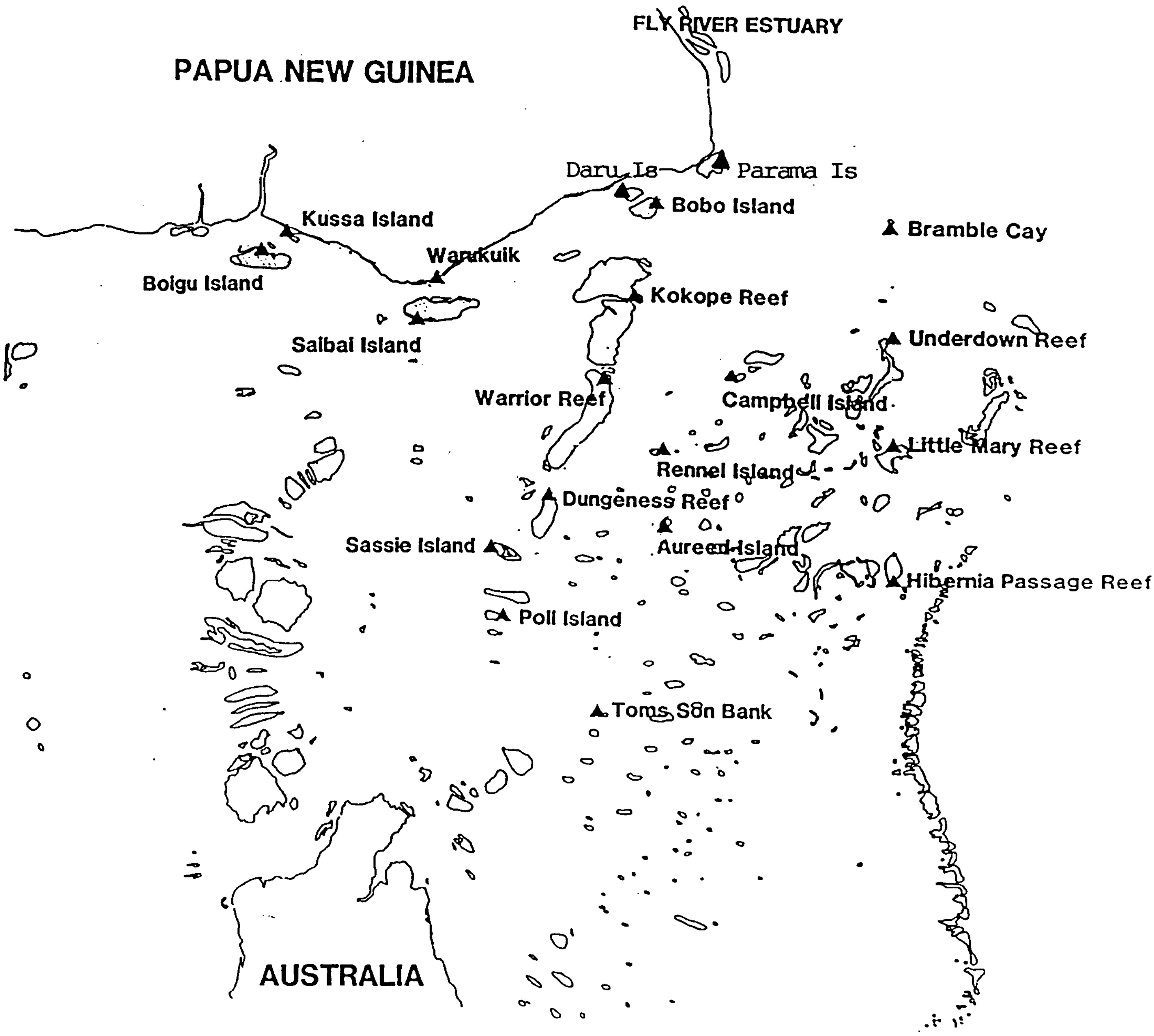


Figure 2.1. Collecting stations for indicator organisms in the Torres Strait

Table 2.1. Comparison of the effects of two types of handling (laboratory vs ship) on the levels of trace metal in the kidneys of burrowing clams (*T. crocea*). Means are compared by paired t-test with an adjusted alpha significance level of 0.003 [calculated by the Dunn-Sidak method (see Day and Quinn 1988), i.e. $\alpha_{wklj} = 1\text{-}0.95^{1/r}$, r = 16 (number of metals tested)]; df = 4 for each test; SD = standard deviation; N = 5 for each method at each station.

Station: Kokope Rf

Method:	Laboratory		Ship		Comparison	
Metal	**Mean**	**SD**	**Mean**	**SD**	**t**	**P**
Ag	6.92	0.942	11.78	7.122	-1.49	0.2102
Al	4.48	0.466	8.36	8.915	-0.93	0.4033
As	498.00	142.548	728.00	201.172	-4.07	0.0153
Cd	232.00	82.280	234.00	51.284	-0.04	0.9725
Co	150.00	68.191	111.20	22.073	1.15	0.3133
Cr	3.42	0.319	2.46	1.358	1.46	0.2190
Cu	2.68	0.776	3.58	1.580	-1.07	0.3459
Fe	1500.00	291.548	746.00	506.833	4.43	0.0114
Hg	1.01	0.364	1.15	0.524	-0.43	0.6869
Mn	20220.00	2766.225	15600.00	7185.402	1.48	0.2135
Ni	748.00	375.327	504.00	125.020	1.44	0.2242
Pb	31.80	9.094	34.00	13.058	-0.23	0.8272
Se	32.20	11.520	27.80	7.918	0.52	0.6329
Sr	798.00	170.939	1102.00	402.020	-1.4	0.2350
U	1.82	0.589	1.42	0.510	0.84	0.4470
Zn	326.00	119.080	600.00	223.047	-2.02	0.1135

Station: Tom Son's Bank

Method:	Lab		Ship		Comparison	
Metal	**Mean**	**SD**	**Mean**	**SD**	**t**	**P**
Ag	0.34	0.372	0.92	1.158	-0.99	0.3787
Al	4.98	4.519	3.76	0.740	0.64	0.5563
As	558.00	160.997	614.00	328.375	-0.43	0.6902
Cd	42.40	13.520	64.80	23.403	-1.71	0.1629
Co	119.60	29.846	121.60	43.391	-0.08	0.9406
Cr	3.12	0.517	4.06	1.115	-1.31	0.2610
Cu	2.66	1.036	2.40	0.819	0.34	0.7509
Fe	788.00	274.536	1074.00	325.392	-1.34	0.2524
Hg	0.81	0.305	0.95	0.364	-0.7	0.5239
Mn	8840.00	1978.130	13800.00	5486.802	-1.96	0.1222
Ni	1186.00	388.819	2010.00	986.408	-1.42	0.2281
Pb	19.00	8.367	29.40	16.134	-1.14	0.3165
Se	31.60	6.656	32.80	11.454	-0.23	0.8279
Sr	874.00	133.154	722.00	297.523	1.11	0.3305
U	1.57	1.112	2.10	0.604	-0.7	0.5209
Zn	11.90	8.202	13.88	11.598	-0.25	0.8164

Table 2.2. Inter-laboratory comparison of the levels of trace metals (mg/kg dry weight) in burrowing clams (*T. crocea*) collected during the pre-monsoon (N=42) and monsoon (N=34) seasons. Laboratories were compared on a metal-by-metal basis using paired t-test at an adjusted α significance level of 0.004 [calculated by the Dunn-Sidak method (see Day and Quinn 1988), i.e. $\alpha_{adj} = 1\text{-}0.95^{1/r}$, r=13 (number of metals tested)]; df=41 for pre-monsoon and df=33 for monsoon data; SD = standard deviation; * = significant at the adjusted α significance level.

Season:	**Pre-monsoon**					
Lab:	**QDPI-ARI**		**AGAL**			
Metal	**Mean**	**SD**	**Mean**	**SD**	**t**	**P**
Al	24.13	39.874	16.76	29.027	1.97	0.0551
As	584.76	190.240	600.95	180.444	-0.73	0.4688
Cd	102.19	99.716	99.32	93.762	0.96	0.3425
Co	156.88	55.529	151.45	51.128	2.15	0.0373
Cr	4.79	2.139	4.54	2.101	3.69	0.0007*
Cu	2.81	1.638	2.88	1.520	-0.48	0.6313
Fe	1467.14	559.365	1280.87	656.217	4.26	0.0001*
Hg	0.78	0.455	0.94	0.383	-3.56	0.001*
Mn	15828.57	6572.867	15148.57	5428.584	1.16	0.2509
Ni	1558.81	783.576	1576.52	841.887	-0.64	0.5234
Pb	30.41	12.529	24.71	9.833	7.42	<0.0001*
Se	61.95	12.006	34.81	10.282	14.8	<0.0001*
Zn	115.02	228.670	108.19	219.674	2.18	0.0354
Season:	**Monsoon**					
Lab:	**QDPI-ARI**		**AGAL**			
Metal	**Mean**	**SD**	**Mean**	**SD**	**t**	**P**
Al	5.52	4.380	4.98	4.010	1.83	0.076
As	575.59	167.824	591.03	172.306	-2.55	0.0158
Cd	103.70	84.471	103.67	81.323	0.02	0.9829
Co	130.76	45.469	139.82	48.667	-6.28	<0.0001*
Cr	4.02	2.121	3.91	1.977	0.82	0.4206
Cu	3.27	4.907	3.25	4.732	0.29	0.7731
Fe	999.71	427.087	1117.59	442.835	-2.01	0.0521
Hg	0.80	0.327	0.87	0.346	-3.28	0.0024*
Mn	16273.53	8736.316	17305.00	8897.315	-2.84	0.0077
Ni	1185.00	657.499	1339.56	726.870	-7.54	<0.0001*
Pb	28.59	10.520	29.03	10.576	-1.51	0.1418
Se	28.35	8.030	27.62	6.145	0.84	0.4083
Zn	208.82	290.206	234.56	307.445	-3.89	0.0005*

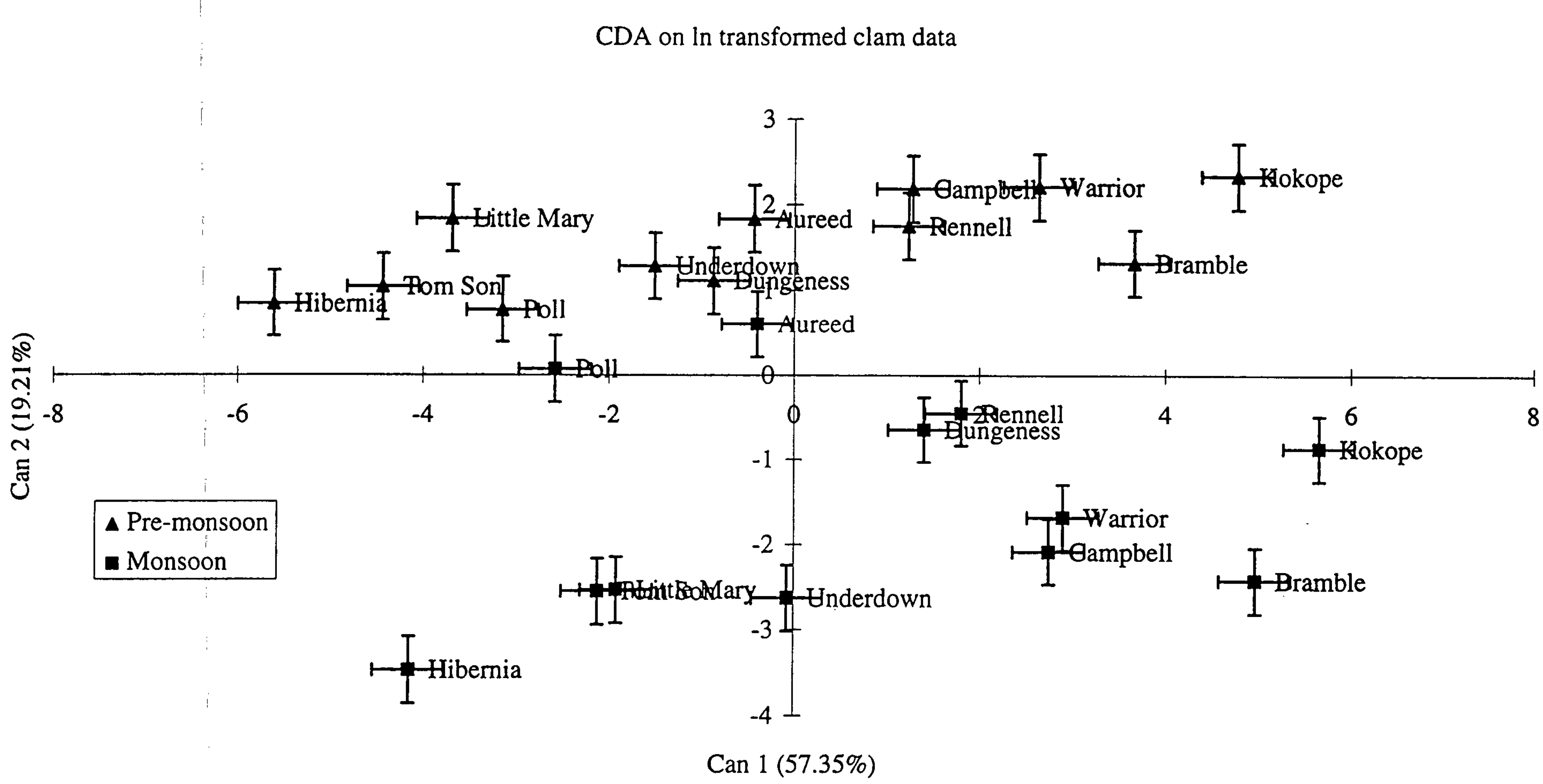


Figure 2.2. Canonical discriminant analysis (CDA) reduced plot of trace metal concentrations in burrowing clams (*T. Crocea*) in Torres Strait in pre-monsoon and monsoon seasons. Bars around each station are 95% confidence intervals.

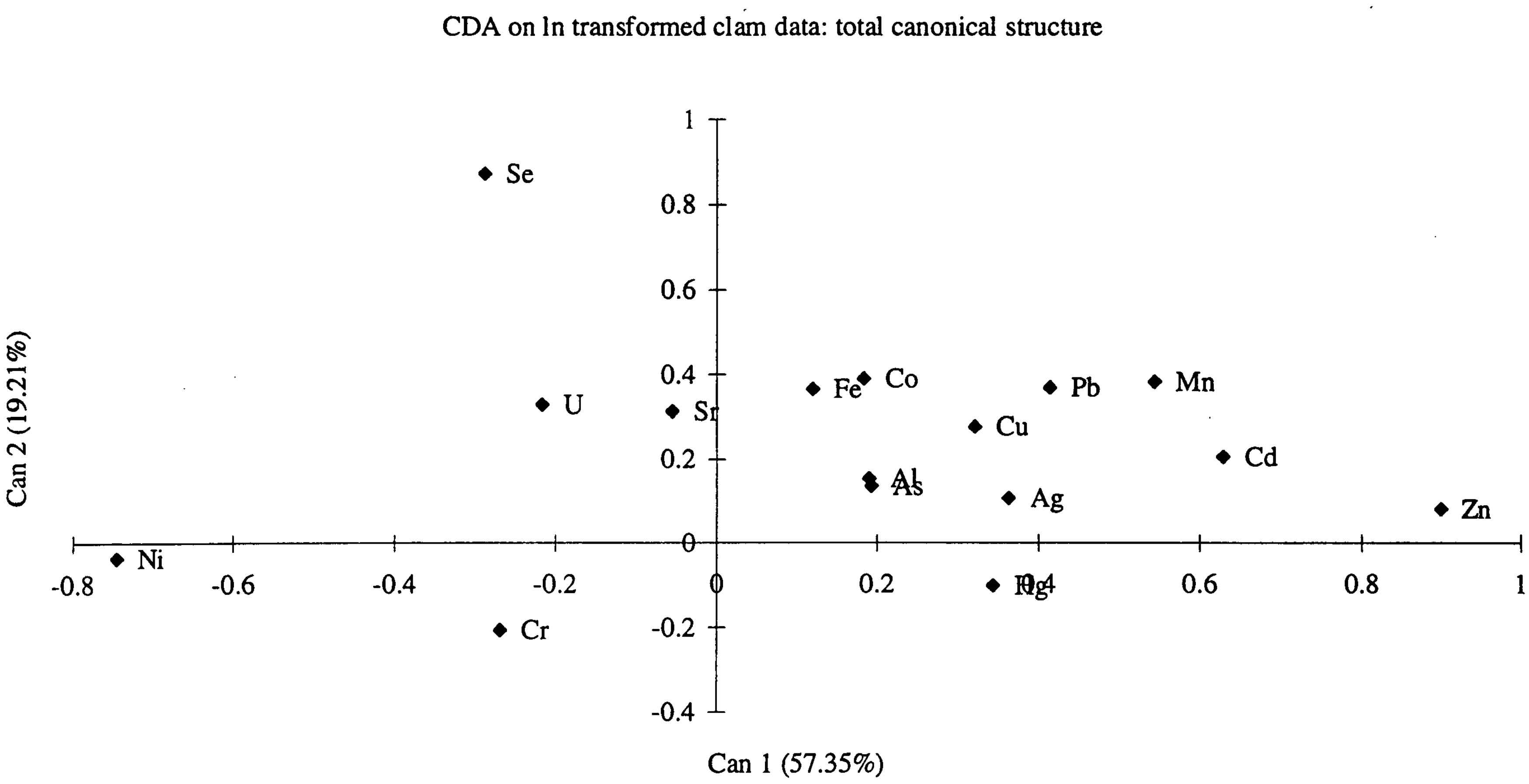
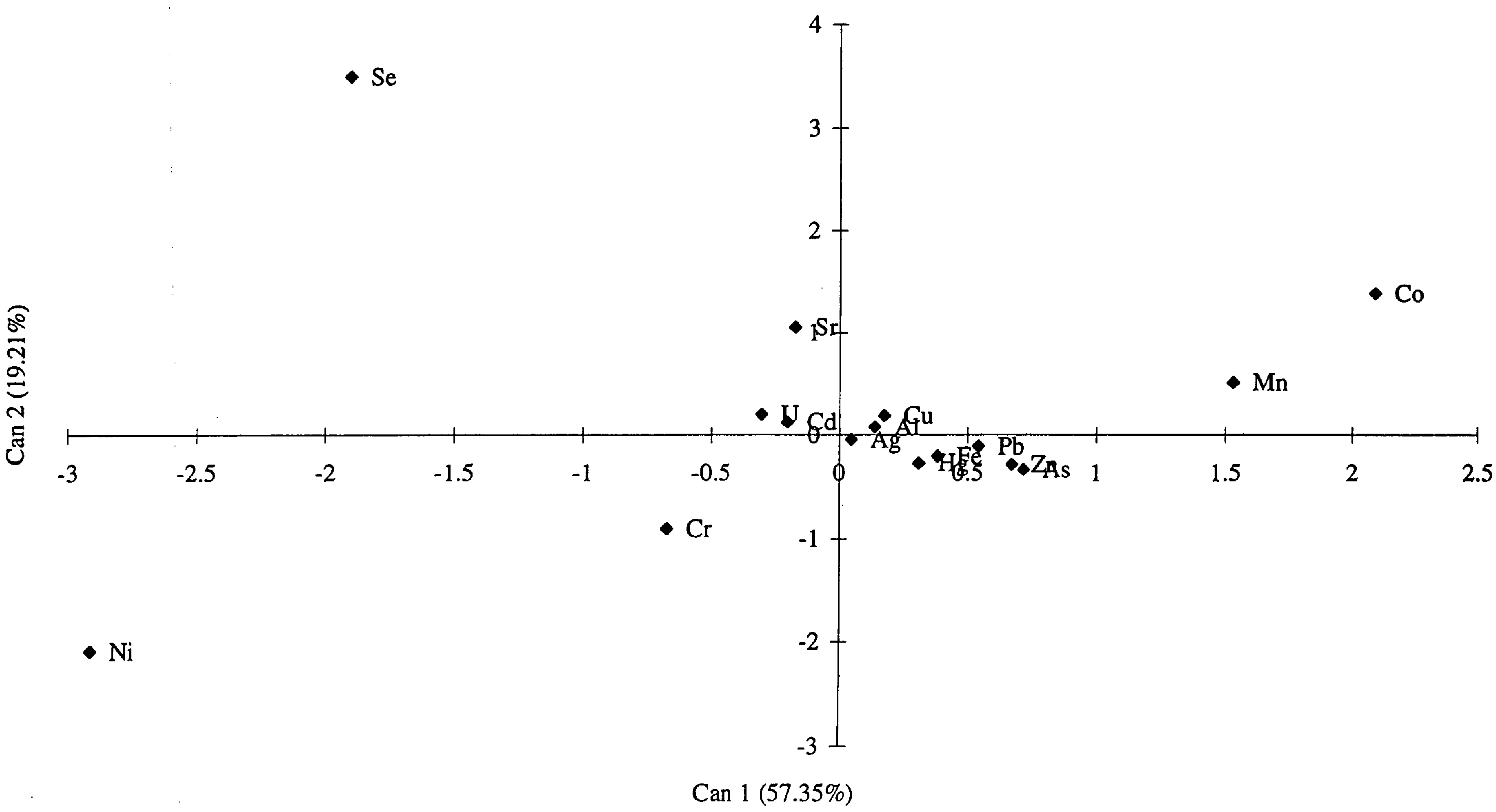


Figure 2.3. Plots of structural coefficients (this page) and canonical coefficients (following page) as a basis for explaining the patterns shown in the reduced plot in figure 2.2.

CDA on ln transformed clam data: raw canonical coefficients



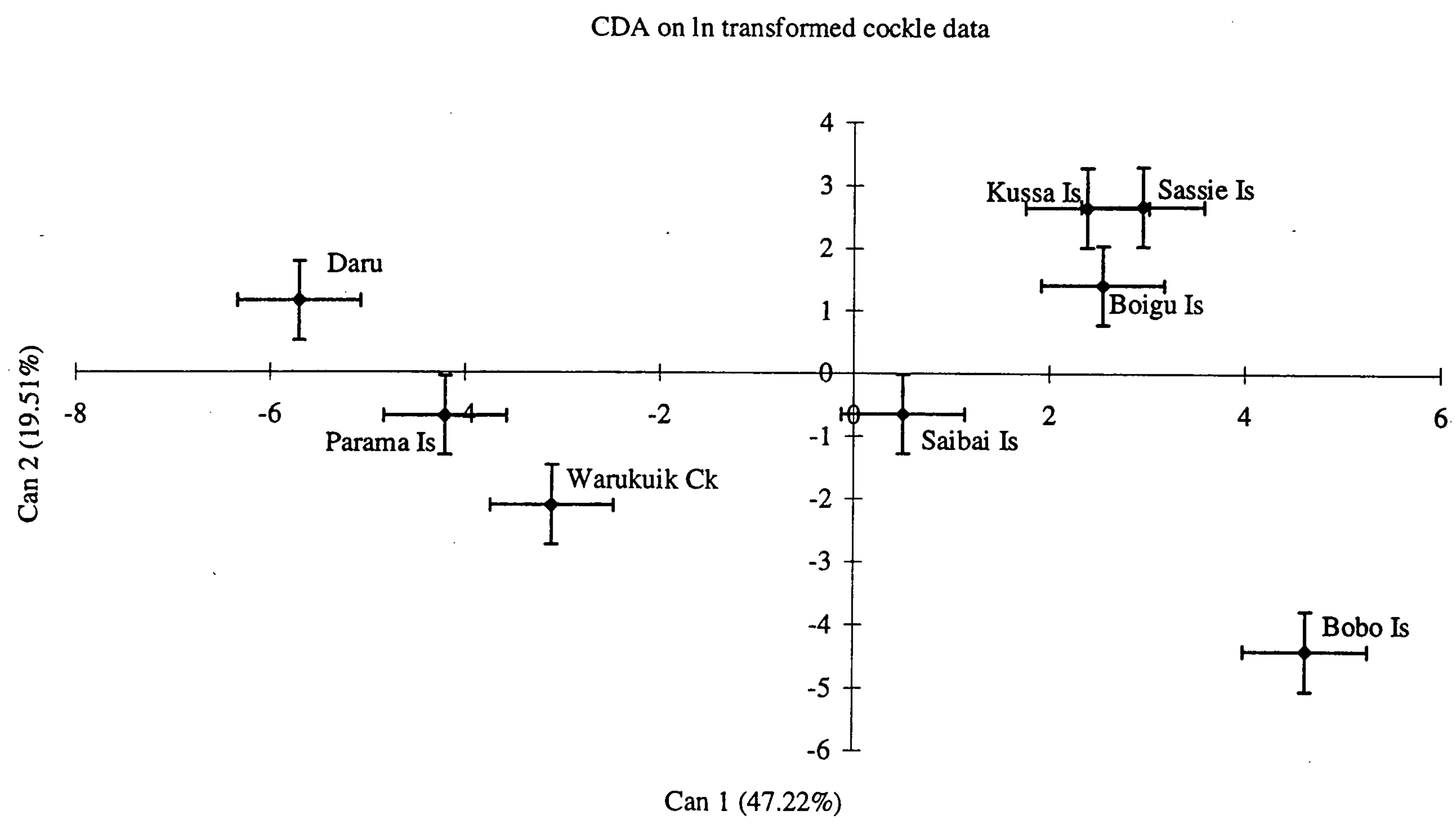


Figure 2.4. Canonical discriminant analysis (CDA) reduced plot, based on concentrations of trace metals in the mangrove cockle (*Polymesoda erosa*) collected during the pre-monsoon in Torres Strait. Bars around stations are 95% confidence intervals.

CDA on ln transformed cockle data: total canonical structure

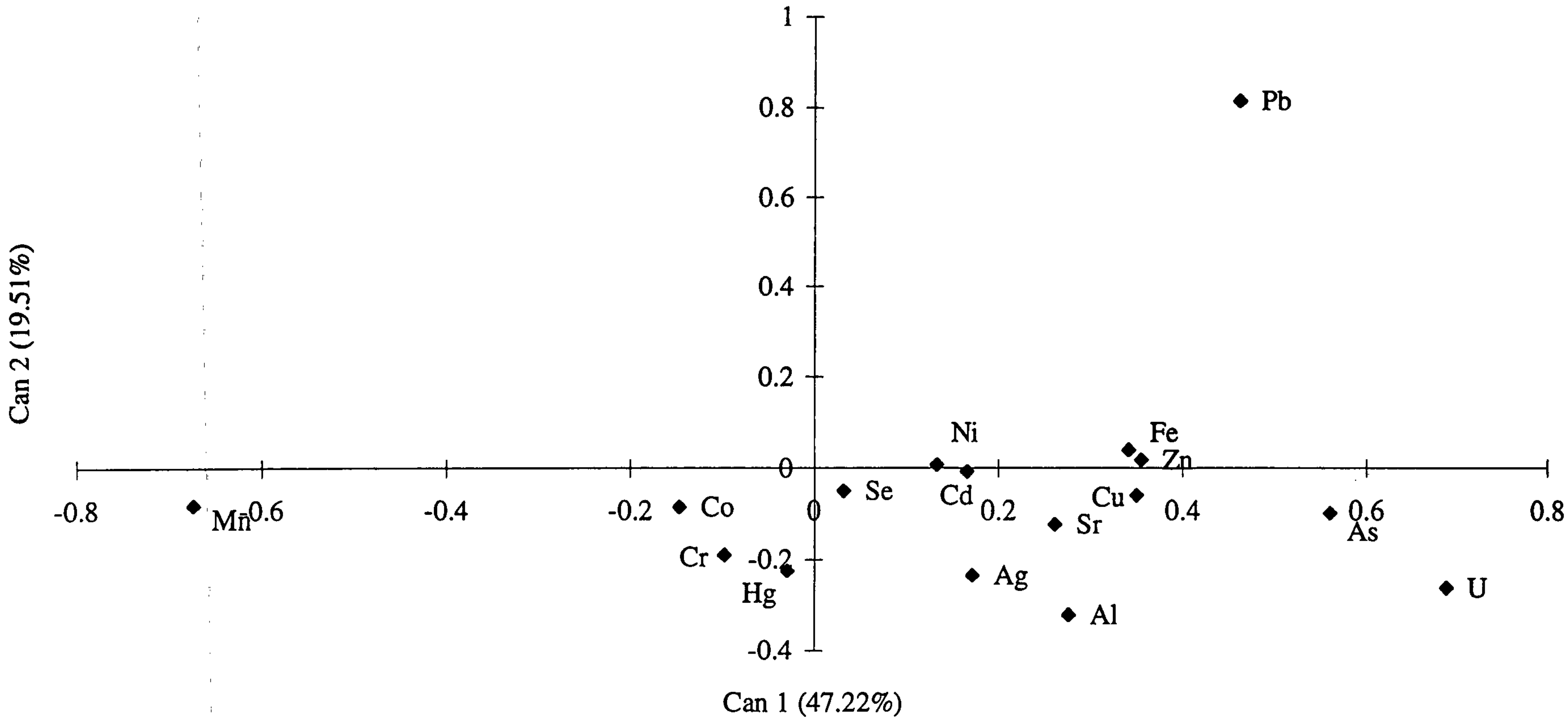
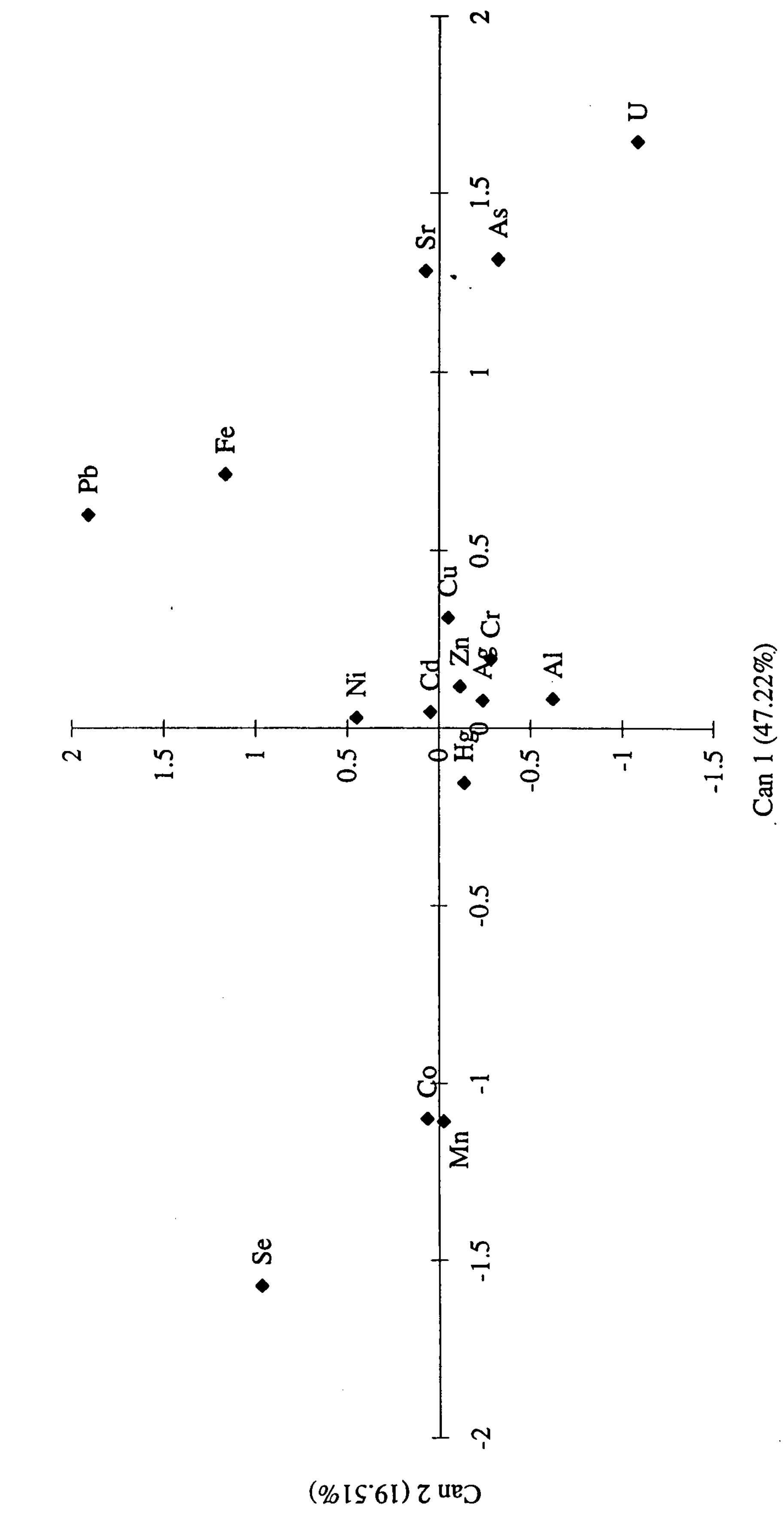


Figure 2.5. Plots of structural coefficients (this page) and canonical coefficients (following page) as a basis for explaining the patterns shown in the reduced plot in figure 2.4.

CDA on ln transformed cockle data: raw canonical coefficients



3. TRACE METALS IN THE TRADITIONAL SEAFOODS OF THE TORRES STRAIT

BACKGROUND

The report of the Pilot Study of the Torres Strait Baseline Study (TSBS) included preliminary information on the levels of trace metals in some of the seafoods commonly eaten by Torres Strait Islanders (Dight and Gladstone 1993). Twenty six species of reef fishes, crustaceans and molluscs were collected, as well as green turtle and dugong, over a period of nine months from June 1991.

Levels of trace metals were low in most species, compared to the Maximum Permitted Concentrations (MPC; National Food Authority, 1994). There were some notable exceptions, however, including the culturally significant dugong and turtle. Cadmium, copper and mercury were high in some or all tissues tested (kidney, liver, intestine, muscle) from green turtles. A similar pattern emerged for dugong: cadmium, copper, mercury, selenium and zinc were high in some or all tissues. Cadmium was the metal most elevated in both turtle and dugong.

Two species of sardines had levels of cadmium and selenium which were high, but based on a limited number of specimens.

These samples were collected as part of the Pilot Study and consequently the number of specimens was small. For example, only one dugong and two turtles were collected. This suggestion of elevated levels led to more specimens and additional species being collected as part of the much larger Main Study. It is those results which are reported here.

METHODS AND MATERIALS

Sample Collection and Preparation

A total of 618 samples from 43 species were collected over two sampling periods: October-December 1992 and February-May 1993. Funding constraints limited the number of samples which could be analysed to 195 from 19 species (see table 3.1) collected between October and December 1992, from the locations shown in figure 3.1.

Specimens were collected by Torres Strait Islanders using their normal techniques, or from commercial fishermen who were capturing the same species. After collection, and unless stated otherwise, samples were handled in the following ways: samples were washed in clean seawater, double-bagged, labelled, then either frozen or placed on ice for transfer by air to the lab on Horn Island where they were frozen. Some samples of fish and crustacean (crayfish and mud crab) were cooked prior to freezing.

The different animal groups collected were handled in the following ways:

Fishes

Samples of fishes were captured by Islanders using either hand line, gill net, or by trolling, or were purchased from local markets. Species and locations are listed in table 3.1. Muscle portions for analysis were taken: from freshly caught specimens (the portion was immediately frozen); from whole and gutted fish which had been frozen immediately after capture; from fresh whole fish which had been grilled (the cooked portion was immediately frozen). Muscle portions from freshly caught fish were taken from the caudal peduncle; muscle overlying the rib cage was taken from cooked samples. In one case a sample of gut was analysed from a fish which had been frozen whole.

Mangrove Cockle (Polymesoda erosa)

Mangrove cockles were collected by Islanders, by hand, in mangrove stands from eight different locations throughout the Torres Strait. Prior to chemical analysis the samples were thawed, opened, and the digestive tract opened and all mud washed out. Trace metal levels were determined for whole samples.

Mud Crab (Scylla serrata)

Five mud crabs were collected by hand from around Boigu Island. All specimens were boiled, to simulate the normal cooking procedure, then frozen. Muscle tissue from inside the carapace was tested for trace metal content.

Crayfish (Panulirus ornatus)

Crayfish were obtained from commercial collectors, who had speared them. Tails and heads were frozen immediately; a sub-sample of heads was boiled for fifteen minutes (to simulate cooking), then frozen prior to analysis. A portion of tail muscle was analysed for trace metal content; whole heads were ground up prior to analysis. A consequence of this technique is that the metal load detected for crayfish heads will be a combination of the metal loads of the shell and the soft tissues. However, it is the hepatopancreas which is eaten from the heads. The metal content of hepatopancreas was estimated separately by subtracting estimates of shell metal loads (reported in Evans-Illidge *in prep*) from total sample metal loads.

Dugong (Dugong dugon)

Samples of dugong tissue were collected from animals which had been recently harpooned from the locations listed in table 3.1, or from animals for sale in the Daru market. The following commonly eaten tissues were analysed: muscle (taken just posterior to the anus), kidney, liver (from the left lobe), intestine (from the middle portion).

Green Turtle (Chelonia mydas)

Samples of plastron muscle, liver, kidney and intestine were taken from green turtles which had been freshly caught either by hand of by spearing, from the locations listed in table 3.1.

Trace Metal Analysis

Trace metal analysis was undertaken by the Animal Research Institute of the Queensland Department of Primary Industries. Inductively Coupled Mass Spectrometry (ICP-MS) was used to determine concentrations of aluminium (Al), total arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), silver (Ag), strontium (Sr), uranium (U) and zinc (Zn). The complete analytical procedures are detailed in appendix 7. Metal levels on both a wet and dry weight basis were determined; however, wet weight levels only are reported here.

Metal levels of some samples were below detection limits. When calculating mean metal levels of a number of samples which included samples where levels were below the detection limits, a value for these samples midway between the detection limit and zero was substituted. This is in agreement with the procedures used in the Market Basket Survey (Stenhouse 1991) and the Pilot Study (Dight and Gladstone 1993).

Comparisons with Standards

Reporting and discussion will concentrate on those metals normally considered to be relevant to human health and for which appropriate standards exist. These metals are arsenic, cadmium, copper, lead, mercury, selenium and zinc.

The potential health implications of high levels of some trace metals were assessed by calculating the amounts of each tissue which could be consumed in one week without exceeding the Provisional Tolerable Weekly Intake (PTWI) for that metal. PTWI values (in µg/kg body weight/week) used in this report were: cadmium 7; lead 25; copper 3500; mercury 5 (Stenhouse 1992). WHO (1987) recommends a selenium intake of 50-200 µg per day for adults; for this study a conservative 125 µg daily intake was used (i.e. maximum safe weekly intake of 0.875 mg). Calculations were done for the following age and sex weight categories: adult male 75.0 kg; adult female 59.1 kg; 12 year old boy 39.78 kg; 12 year old girl 41.53 kg (Stenhouse 1992). Calculations for cadmium and mercury take into account the intake of these metals from other dietary sources (from the 1990 Market Basket Survey, Stenhouse 1991). Maximum safe levels of consumption for turtle and dugong tissues were calculated by combining the results of the Pilot (Dight and Gladstone 1993) and Main studies, because of the small number of samples of each. Arithmetic means were calculated when sample sizes exceeded one.

Metal levels are also compared with, but for reference only, the Maximum Permitted Concentration (the MPC) for each metal as set out in Food Standard A12 (National Food Authority 1994). MPC values are only relevant for foods which are sold and are not designed for use as a health standard. MPC values exist for fish, crustacean, and molluscs; however, no values exist for samples of meat and offal taken from dugong and turtle. The MPC value used for these samples was the 'All other foods' category for each metal. The MPC for arsenic is based on inorganic arsenic; however, total arsenic was measured in this study. For the purposes of this Study it was assumed that inorganic arsenic represents 1.3% of total arsenic, which is the average of a range of percentages reported by Edmonds and Francesconi (1993) for a similar range of marine animals (fishes, crustaceans, molluscs).

RESULTS

Summary results of the levels of metals relevant to human health, for the different food groups, are in appendices 18 to 22 at the end of this chapter, and safe levels of consumption are in appendix 23.

Fishes

Samples from 15 species of fishes were analysed, representing a total of 44 samples. Appendix 18 is a summary of the results for the metal levels of all fishes sampled, for those metals relevant to human health. Metal levels are low in most species and tissues tested, including cooked specimens. The only exceptions to this are mercury in barramundi (*Lates calcarifer*) muscle; cadmium and copper in parrotfish (*Scarus dimidiatus*) muscle; and selenium in mullet (*Valamugil seheli*) gut. If these tissues were sold commercially the levels of these metals would exceed the MPC values. Weekly consumption of between 9 and 25 g of parrotfish muscle, between 112 and 203 g of barramundi muscle, and 673 g of mullet gut, will equal the PTWI for cadmium, mercury and selenium respectively (appendix 23). However, these results should be treated cautiously as they are derived from only 1-2 specimens of each species.

Mangrove Cockle (*Polymesoda erosa*)

A total of 120 mangrove cockles were collected from eight locations in the central and northern Torres Strait (appendix 19). Mean levels of all metals were low. Selenium levels of some individual specimens (e.g. from Warukuik Creek and Daru) were high; however, the infrequency of such specimens in the total number collected suggests that they probably have insignificant health implications.

Crustaceans

Mud Crab (Scylla serrata)

Mean levels of all metals were low (appendix 20). However, as the ranges show, copper in two specimens (9.1 mg/kg, 11.0 mg/kg) and selenium in two specimens (1.2 mg/kg, 1.0 mg/kg) were at or near the respective MPC values of 10.0 and 1.0 mg/kg.

Crayfish (Panulirus ornatus)

Metal levels varied with tissue type and cooking. In crayfish tail muscle the mean and individual levels of all metals were low (appendix 20). Total arsenic levels in crayfish tails were the highest recorded amongst all specimens analysed for this study; however, when total arsenic was converted to inorganic arsenic the values were low.

Cadmium in fresh crayfish heads was greater than the levels in tail muscle. There was, however, a great difference between the two specimens analysed (2.1 mg/kg and 0.02 mg/kg) which elevated the mean value. All other metals in fresh crayfish heads were low.

Cooking of crayfish heads elevated the levels of cadmium, copper and zinc (appendix 20). If boiled crayfish heads were sold commercially the levels of cadmium, copper and possibly selenium would exceed the MPC values for these metals. The major source of metals in crayfish heads is the hepatopancreas, which in the Torres Strait is commonly eaten whole after cooking. The concentration of metals in the hepatopancreas can be approximated by subtracting the metal contents of shell for cadmium (0.01 mg/kg) and copper (1.27 mg/kg) from the total head loads (from values reported in Evans-Illidge in *prep*). This approximation does not take into account the levels of these metals in gill tissue (Rainbow and Moore 1986) and may bias the result upwards; however, no information is available on gill levels in this species.

Although the copper levels in the hepatopancreas are high, they are unlikely to have health implications as between 36.9 and 69.7 kg would need to be consumed in one week to put the consumer at the PTWI (appendix 23). However, smaller quantities, between 79 and 222 g per week (depending on the consumer's sex and weight), will put consumers at the PTWI for cadmium.

Dugong (*Dugong dugon*)

Tissues from three dugong collected from different locations throughout the Torres Strait were analysed. Cadmium, copper, selenium and zinc levels were high in one or more tissues (appendix 21). Levels of these metals varied amongst the five tissue types; however, levels in liver and kidney were generally higher than other tissue types. The relative levels of metals for which there is an MPC, in the different tissues, is shown below:

Arsenic:	muscle<intestine<kidney<liver<muscle+fat
Cadmium:	muscle<muscle+fat<intestine<liver<kidney
Copper:	muscle<intestine<kidney<muscle+fat<liver
Mercury	muscle=muscle+fat=intestine<kidney<liver
Lead:	muscle+fat<intestine<muscle<kidney<liver
Selenium:	muscle<intestine<muscle+fat<liver<kidney
Zinc:	muscle+fat<muscle<intestine<kidney<liver

Levels of cadmium, copper, selenium and zinc in liver; cadmium and selenium in kidney; cadmium in intestine, and possibly mercury in liver would preclude these tissues from sale as food because of violations of the MPC for these metals.

Copper, selenium and zinc levels, although high, were unlikely to have health implications, because of the large quantities of tissue that must be eaten each week for these metals to exceed the PTWI (appendix 23). However, consumption of quite small quantities of liver (between 17 and 47 g per week) and kidney (between 13 and 37 g per week) will put the consumer at the PTWI for cadmium (appendix 23).

Green Turtle (*Chelonia mydas*)

Tissue samples from five turtles collected from different locations throughout the Torres Strait were tested. Cadmium, copper, mercury, and selenium levels were high in one or more of the different tissue types (appendix 22). Levels varied amongst the four tissue types; however, the mean levels were always greatest in either kidney or liver, or both. The relative levels of metals for which there is an MPC, in the different tissues, are:

Arsenic:	kidney<muscle<liver<intestine
Cadmium:	muscle<intestine<liver<kidney
Copper:	intestine<muscle<kidney<liver
Mercury	muscle<kidney<intestine<liver
Lead:	intestine<kidney<muscle<liver
Selenium:	muscle<intestine<kidney<liver
Zinc:	muscle<intestine<kidney<liver

All turtle tissues would be unfit for sale because they exceed the MPC for one or more of the following metals: cadmium, copper, mercury and selenium.

The levels of copper, mercury and selenium are unlikely to have health implications because of the large quantities of tissue which must be consumed each week for the intake of these metals to exceed the PTWI (appendix 23). However, weekly consumption of between 4 and 11 g of kidney, or between 10 and 28 g of liver will give the consumer a cadmium intake equal to the PTWI. In comparison, weekly consumption of between 93 and 262 g of turtle muscle will give the consumer a cadmium intake equal to the PTWI.

DISCUSSION

Comparisons with the Pilot Study

This Main Study surveyed the levels of trace metals in a number of the traditional seafoods consumed in the Torres Strait. The majority of specimens tested had low levels of trace metals, supporting the preliminary findings reported in the Pilot Study (Dight and Gladstone 1993). To summarise the present results, 13 of the 15 species of fishes tested had low levels of all metals. A single specimen of parrotfish had elevated levels of cadmium and copper; a single specimen of barramundi showed elevated levels of mercury. This parrotfish (*Scarus dimidiatus*) was not tested in the Pilot Study and mercury was not elevated in a single specimen of barramundi tested in the Pilot Study. These results should be treated as being inconclusive until more specimens are tested.

Amongst the fishes tested for the Pilot Study three specimens of Murray Island sardine (*Harengula ovalis*) showed high levels of cadmium and selenium. The same species was tested for the Main Study using a larger sample size (N = 15), but collected at Horn Island. Individual and mean levels of all metals were low; cadmium levels, except for one sample, were all below the detection limits. The Pilot Study results caused concern amongst the inhabitants of Murray Island who frequently eat this species (V McGrath pers. comm.), and so it is worthwhile exploring these differences in some detail. The difference in results between the Pilot and Main Studies could reflect a true geographic difference in metal levels between Murray and Horn Islands. Other results, however, from the Pilot Study revealed no difference in the sediment levels of cadmium and selenium between two stations close to Murray and Horn Islands (Dight and Gladstone 1993). In addition, fishes are efficient regulators of most metals and their tissues do not normally reflect geographic trends in metal levels (Phillips 1980). The observed difference could be caused by contamination of the Murray Island samples during collection or storage. Alternatively, as food is a major source of metals in fishes (Bryan 1984), there could be a difference in the diet of *H. ovalis* between Horn and Murray Islands as these specimens were tested whole (i.e. including the gut). Locational differences in cadmium levels have been attributed to diet variations for another species of fish on the Great Barrier Reef (Burdon-Jones and Denton 1984). Further testing of specimens collected from Murray Island is warranted.

Mean levels of all metals were low in mangrove cockles, mud crabs, and fresh crayfish tails, supporting the results for mangrove cockles and crayfish tails reported in the Pilot Study (mud crabs were not investigated in the Pilot Study). The results for fresh crayfish tails also agree with results from the Commercial Fisheries study (Evans-Illidge *in prep*) where a much larger sample size was tested.

There was some concern expressed in the Pilot Study about the high levels of total arsenic in the tail muscle of two species of crayfish. However, applying the conversion of 1.3% inorganic arsenic (Edmonds and Francesconi 1993), the levels of inorganic arsenic in *P. ornatus* tails were low, but the level in a single specimen of *P. versicolor* is higher, and approached the MPC.

Fresh crayfish heads had high levels of cadmium, and cooked heads had higher cadmium and copper levels (crayfish heads were not investigated in the Pilot Study). The high levels of metals in the head reflect the importance of the hepatopancreas as a metal storage organ, especially for copper to be used in haemocyanin (Rainbow 1988). Damage to the hepatopancreas is the most likely reason for increased levels of copper in cooked specimens. Increases following cooking in body muscle cadmium content (often exceeding the MPC) have also been reported for spanner crabs (Rayment 1988; Slattery et al 1992).

Dugong liver had high levels of cadmium, copper, selenium, zinc and possibly mercury. Kidney samples had elevated levels of cadmium and selenium; and one sample of intestine had high cadmium levels. Except for zinc in liver tissue, the same trends were reported in the Pilot Study from analysis of tissues from one animal.

All turtle tissues showed elevated levels of one or more metals; liver specimens had high levels of cadmium, copper, mercury and selenium; kidney specimens had high levels of cadmium, selenium, and possibly mercury; some samples of intestine and muscle had elevated mercury.

Only cadmium, copper and mercury were elevated in two specimens examined for the Pilot Study.

Health Implications

Heavy metal levels in large marine animals are important because of the potential health effects (Black 1988) in traditional societies where these animals are still hunted. It is beyond the scope of this report to comment on the potential impacts on human health from consuming traditional seafoods in the Torres Strait. However, because these results represent the first extensive survey of metal levels in the traditional seafoods of the Torres Strait, they should be utilised to highlight potential areas for concern and future action by appropriate specialists.

Potential health implications were assessed by reference to the PTWI for those foods where metal levels were high (summarised in appendix 23). The following foods were identified with high levels of some trace metals: barramundi and parrotfish muscle, mullet gut, Murray Island sardines, boiled crayfish heads, dugong liver and kidney, and all turtle tissues.

Single specimens only of barramundi and parrotfish were investigated. The parrotfish tested here (*Scarus dimidiatus*) was not recorded in an extensive survey of the fishes commonly caught and eaten by Torres Strait Islanders and probably does not require further investigation; similarly, barramundi (*Lates calcarifer*) represented only 1.7% of total catch (Harris et al 1994). Barramundi is, however, an important commercial and recreational species in the fisheries of northern Australia and therefore deserves further investigation. Other studies have determined elevated levels of mercury in barramundi from Papua New Guinea (Kyle and Ghani 1985, Currey et al 1992).

Boiled crayfish heads were identified as a source of high levels of cadmium, most of which originated in the hepatopancreas. Torres Strait Islanders sell the high value crayfish tails, then boil the heads and eat the hepatopancreas whole (V McGrath pers. comm.). Crayfish caught most frequently by Torres Strait Islanders are between 100 and 115 mm carapace length, with average weights of between 877.0 g and 1098.5 g (R. Pitcher, unpublished data). The hepatopancreas represents approximately 10% of total body weight (R. Pitcher pers. comm.), and consumption of small amounts could lead to high intake of some trace metals. Actual consumption rates are unknown.

Weekly consumption of relatively small quantities of dugong liver and kidney, and of all tissues of the green turtle, will exceed the PTWI for cadmium. The levels of metals in the turtle and dugong samples collected for this Study are probably representative of the levels to which Torres Strait Islanders are exposed, because the sizes of turtle and dugong sampled are within the size ranges of the usual catches for both species (Johannes and MacFarlane 1991; Harris et al 1994). Previous studies (cited in Johannes and MacFarlane 1991) have determined the daily consumption rates of dugong and turtle muscle at several locations in the Torres Strait. The results suggest that at the time of those studies weekly consumption of dugong muscle at three locations (Boigu Island: 0.233 kg per week; Yorke Island: 0.042 kg per week; Badu, Moa and Mabuiag Islands: 1.89 kg per week) did not exceed the PTWI for any metal. By contrast, weekly consumption of turtle muscle at Yorke Island (0.69 kg) exceeded the PTWI for cadmium; Mabuiag Island consumption (0.91 kg) exceeded the PTWI for cadmium and selenium; Boigu Island consumption (0.82 kg) exceeded the PTWI for cadmium and possibly selenium; Kubin community consumption (1.96 kg) exceeded the PTWI for cadmium, selenium, and was near the PTWI for copper for boys and girls. Average weekly consumption of turtle muscle throughout the Torres Strait (0.87 kg) exceeded the PTWI for cadmium and selenium.

The studies referred to in the preceding paragraph contained data only on the consumption of muscle. Current consumption rates of the muscle and other tissues are unknown but can be estimated using data from a recent study on catch rates of turtle in the Torres Strait (Harris et al 1994), and organ weights as a percentage of total body weight (Rebel 1974; unfortunately, comparative information of the relative weights of dugong tissues is not available). This data (see table 3.2) shows that, on average, sufficient quantities of all turtle tissues, except kidney, are available each week in the Torres Strait for consumers to exceed the PTWI for cadmium, but not for copper, mercury or selenium.

These results should be interpreted cautiously and not taken to indicate that a public heath problem currently exists in the Torres Strait. The current limitations of these results include: (1) small sample size. Additional samples were collected for the Main Study; however even when the Pilot and Main Study results were combined to estimate safe weekly consumption rates (appendix 23), data from only three dugong and seven turtles were available. Further samples were collected for the Main Study and are still in storage but were not analysed because of funding constraints; (2) the calculation of safe levels of consumption does not take into account the levels of consumption of other foods, which are also sources of trace metals; (3) interactions with other chemicals. Studies have shown that absorption of cadmium is influenced by other dietary factors such as the gut concentrations of protein, calcium, vitamin D and zinc (Black 1988, Koh 1988) and also the age and sex of the consumer (Koh 1988); (4) consumption rates of these foods are unknown. Health problems associated with consuming excess levels of heavy metals will occur when the PTWI is consistently exceeded. Catch rate data from two studies (Johannes and MacFarlane 1991; Harris et al 1994) has shown that catches of both turtle and dugong vary considerably between locations in the Torres Strait, and vary over time. Information on actual consumption rates collected over a long period of time is urgently needed. This information needs to be complemented by information on the consumption rates of all other foods to obtain a more realistic calculation of actual trace metal intake.

Sources of Elevated Trace Metals

An important reason for establishing the TSBS was to investigate the concern expressed by Torres Strait communities that their traditional seafoods could eventually become contaminated with trace metals from the Fly River. Investigating this involves establishing the levels of trace metals in traditional seafoods, identifying the potential source(s) of those metals with elevated levels using other information collected as part of the TSBS, and a consideration of the natural history of those animals with elevated metal levels in their tissues.

Naturally occurring elevated levels of trace metals in tissues of other large marine animals have been attributed to dietary sources (Miles and Hills 1994). Dugong and green turtle are herbivores feeding on seagrasses and some algae. It is possible that the elevated levels of cadmium in these two animals originate from high levels in dietary items and the incidental ingestion of sediment. Cadmium levels in three species of seagrass common in the Torres Strait, *Halophila ovalis* (Denton et al 1980), *Thalassia hemprichii* and *Thalassodnedron ciliatum* (Dight and Gladstone 1993) are low, and close to levels in terrestrial angiosperms and pasture grasses (Denton et al 1980). Sediment levels of cadmium in the Torres Strait are below the levels considered to be normal for unpolluted tropical areas (this report and Dight and Gladstone 1993). Elevated levels of cadmium in these animals could therefore be due to high levels of consumption over a long lifespan.

Sediment results from this study and the Pilot Study indicated that cadmium in the Torres Strait is primarily associated with coarse-grained carbonate sediments of marine origin; in particular, cadmium levels close to the Fly River were the lowest in the Torres Strait.

Comparisons with other studies reveals that the levels of cadmium in dugong and turtle tissues from the Torres Strait are comparable to levels detected in these same tissues from unpolluted areas outside the Torres Strait. Cadmium levels in dugong offal from the Torres Strait are within the range of values reported for dugong from north Queensland coastal waters outside the Torres Strait (Denton et al 1980). Cadmium in dugong tissues exceeds the levels found in other marine mammals (see Denton et al 1980 and references therein, Pena et al 1988, Taylor et al 1989). By comparison, cadmium in dugong muscle occurs at lower levels than in the muscle tissue of sheep and cattle, but it occurs in liver and kidney at levels of at least one order of magnitude greater than in the same tissues of sheep and cattle (Langlands 1988).

Levels of cadmium in Torres Strait green turtle tissues are within the range of values reported for this species in Hawaiian waters (Aguirre et al 1994). No other information on metal levels exists for this species.

In summary, although cadmium levels are elevated in turtle and dugong tissues from the Torres Strait, they are similar to levels reported for the same species from other localities, and it is reasonable to conclude that these high levels are a natural phenomenon. However, the health implications associated with consuming large quantities of food itemes which are naturally high in trace metals needs to be investigated.

Table 3.1. Specimens of community seafoods analysed for the Main Study

GROUP	SPECIES	NAME	ISLAND NAME	LOCATION
FISHES	*Scomberoides commersonianus*	Talang queenfish	Kabar	Warraber Is
	Scomberomorus commerson	Spanish Mackerel	Dubui	Warraber Is
	Caranx ignoblis	Giant trevally	Mathai/gaigee	Warraber Is
	Mugil georgii	Fantail mullet	Murgudlai	Warraber Is
	M. cephalus	Sea mullet	Makerr	Saibai Is
	Choerodon cyanodus	Blue tuskfish	Billa	Warraber Is
	Lutjanus carponotatus	Stripey	Thanab	Warraber Is
	Lethrinus laticaudis	Grass emperor	Poeyad	Bet Is
	Harengula ovalis	Murray Is sardine		Horn Is
	Lates calcarifer	Barramundi		Saibai Is
	Scarus dimidiatus	Yellowbarred parrotfish	Bira	Kokope Rf
	Gnathanodon speciosus	Golden trevally	Kabaro	Kokope Rf
	Amniataba caudavittatus	Yellowtailed perch	Jurrum	Bobo Is
	Hemiramphus far	Garfish	Jabere	Bobo Is
	Valamugil seheli	Bluetailed mullet	Kaworo	Daru
MOLLUSCS	*Polymesoda erosa*	Mangrove cockle	Akul	Sassic Is
				Kussa Is
				Boigu Is
				Saibai Is
				Warukuik Ck
				Bobo Is
				Parama Is
				Daru
CRUSTACEANS	*Scylla serrata*	Mud crab	Gitalai	Boigu Is
	Panulirus ornatus	Crayfish	Kaiar	Saibai Is
				Mabuiag Is
SEA TURTLE	*Chelonia mydas*	Green turtle	Waru	Warraber Is
				Boigu Is
				Saibai Is
				Daru
MAMMAL	*Dugong dugon*	Dugong	Dangal	Mabuiag Is
				Boigu Is
				Daru

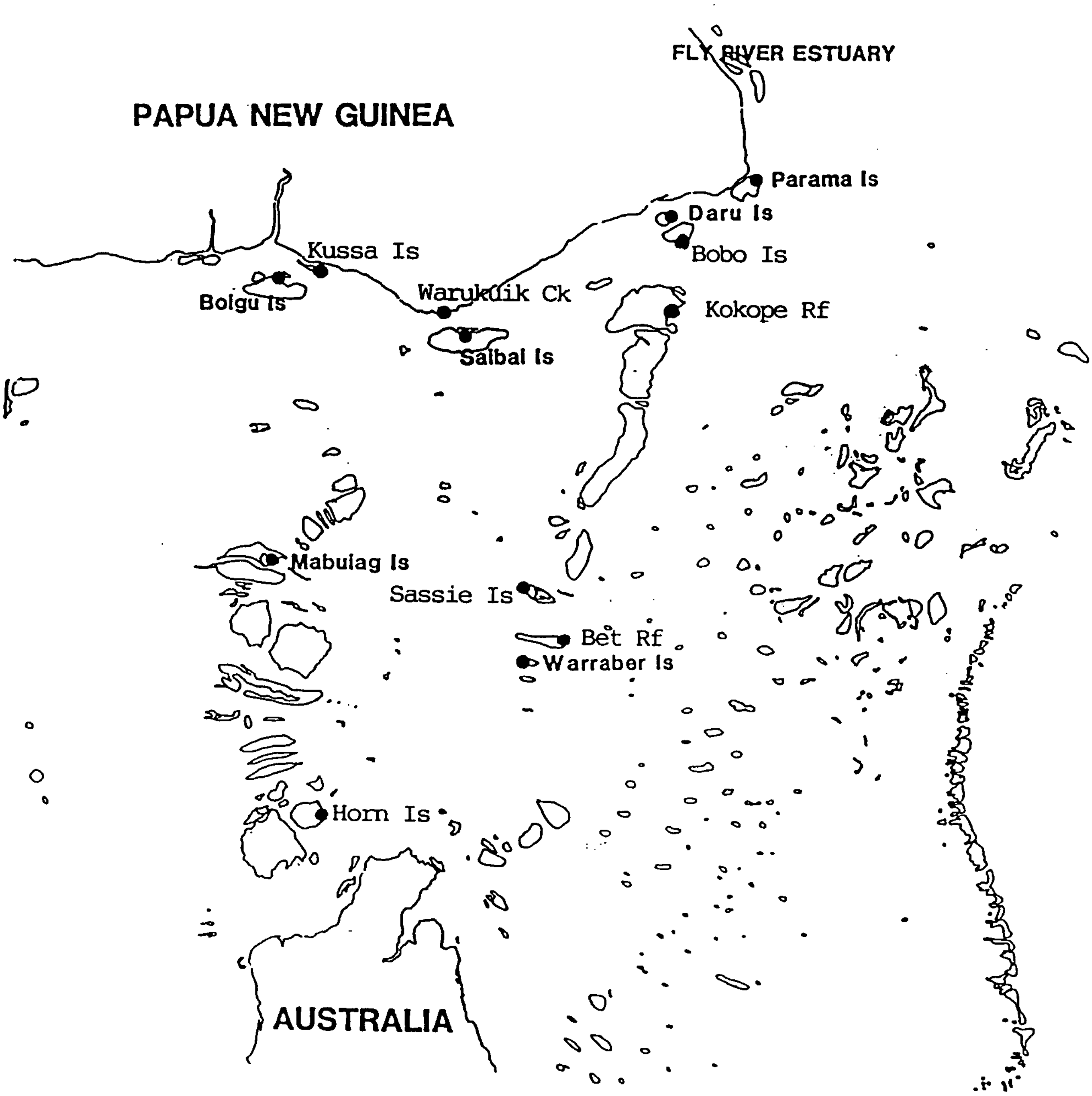


Figure 3.1. Map of the Torres Strait showing locations from which samples were collected

Table 3.2. The potential consumption rates of turtle tissues in the Torres Strait, based on a daily catch of 594 kg (Harris et al 1994); relative organ weights (Rebel 1974), and an estimated population for the outer islands of 3000 persons.

Tissue	Amount available per week (kg)	Maximum potential consumption rate (kg/person/week)
Muscle	2071	0.69
Kidney	7.5	0.0025
Liver	99.8	0.03
Intestine	354.1	0.115

4. FUTURE MONITORING

The initial impetus for establishing the Torres Strait Baseline Study was the concern about possible impacts on the Torres Strait marine environment from mining operations in the Fly River catchment of Papua New Guinea. Assessing the impacts of human activities in the marine environment is a complex process. The process is even more challenging in physically dynamic environments, such as estuarine-oceanic interfaces, where inputs can be unpredictable and variable (this is the situation in the northern Torres Strait). Ideally, assessing the potential impacts of Fly River mining operations on trace metal levels in the Torres Strait would involve comparisons over time (before, during and after the impact) between the Fly River-Torres Strait transect and several other physically similar river-reef transects at similar distances from rivers without mining operations. This situation is not available in the Torres Strait.

Detecting impacts in the Torres Strait from Fly River catchment mining operations will therefore require long-term monitoring at established locations. Long-term monitoring is essential so that the range of natural changes in trace metal levels can be documented, understood and evaluated against potential changes caused by human activities. Data presented in this report on trace metal levels in sediments and indicator organisms[4] will serve as a baseline against which future changes can be assessed. This data was, however, collected only over a single time period and provides little information about the full range of natural variations which are possible.

One of the most important sources of natural variation which needs to be understood is the effect of season. For example, for copper levels in burrowing clams, the amount of variation explained by seasonal effects, 10.24%, was only slightly less than the amount of variation explained by spatial effects, 16.43% (see appendix 10). Although the burrowing clam has been shown to be a reliable indicator of ambient trace metal levels (Burdon-Jones and Denton 1984a, Denton 1987), seasonally varying factors (such as water temperature, currents, salinity, food availability, gonad development) have the potential to affect the uptake of metals (Phillips 1980, Burdon-Jones and Denton 1984a). In addition, there are seasonal differences in the delivery of trace metals into the northern Torres Strait. Fly River water penetrates the northern Torres Strait during the monsoon season, and results of the present study suggests that the timing of this penetration is not predictable within the monsoon season. In summary, at different times of the year the levels of trace metals in an indicator organism such as the burrowing clam will reflect the ambient levels of these metals, and also the combined influence of ambient trace metal levels and other unrelated environmental variables, and biological features of the indicator itself.

These considerations have consequences for the development of a long-term monitoring program, and the interpretation of its results. Understanding the range of natural variations in trace metal levels will only be achieved by regular monitoring, in both seasons of the year, over a long period of time. This should be done, as a minimum, as frequently and at the same times of year as followed in the present study. This will undoubtably reveal considerable variation from year-to-year, especially in the results obtained during the monsoon season (for the reasons outlined above). However, if the monitoring is continued for a sufficiently long period of time, these natural variations will be documented and understood (an alternative, but more expensive option, would be to sample more frequently during the monsoon season as a way of pinpointing more closely the time of greatest influence of the Fly River).

[4] It is not proposed to establish a regular monitoring program for trace metal levels in traditional seafoods. The metal of most concern in traditional seafoods, cadmium, is not attributed to Fly River runoff. Furthermore, levels of cadmium in the food items of greatest concern (green turtle and dugong) probably represent accumulation over many years, are highly variable, and detection of trends associated with human activities would be extremely difficult.

Several sampling issues need to be considered:

(1) *Frequency of monitoring*

It has been suggested (Burdon-Jones and Denton 1984a, p 153) that in 'remote areas' monitoring should be undertaken once every five years. The Torres Strait, however, is a dynamic and variable environment (Dight 1991) and so more frequent sampling is warranted, e.g. every three years.

(2) *Indicator species*

The Pilot Study (Dight and Gladstone 1993) suggested two species of molluscs that were suitable as indicators of dissolved and particulate trace metals respectively, the burrowing clam (*Tridacna crocea*) and the mangrove cockle (*Polymesoda erosa*). Both species should therefore reflect the total metal load available (Dight 1991), and should continue to be collected.

(3) *Sampling locations*

Given that one of the objectives of a long-term monitoring program of this sort in the Torres Strait will be to detect changes in trace metal levels associated with human activities, the sampling program should include stations which could be impacted as well as a number of control stations unlikely to be impacted (for the purposes of the monitoring program the potential changes at impact sites include an increase in the levels of some trace metals, and an increase in the amount of fine sediment). The sampling program followed in the present study (for sediments and indicator organisms) allows for such a comparison, as it includes a group of stations in the northern Torres Strait close to the mouth of the Fly River which are currently influenced by Fly River outflow (levels of trace metals at these stations appeared to be at background levels during this study), and groups of stations throughout the Torres Strait not influenced by the Fly River.

(4) *Detectable and acceptable changes*

The sampling program followed in the present study detected a change over time in the copper levels in burrowing clams of about 19.5%. This is the maximum change that was detected, smaller changes could be detected by the same sampling program. There needs to be discussions amongst scientists, environmental managers, and the Torres Strait community about the magnitude of change detectable that is desirable, and the implications of this for the cost of a long-term monitoring program. If appropriate, the sampling program should be amended to reflect this desired level of detection.

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APPENDIX 1

Preparation Procedures and Analytical Methods Associated with Sediment Samples from the Torres Strait Baseline Study

Prepared by G. A. Barry, Queensland Department of Primary Industries

The following procedures relate to samples taken for the Main Study.

Sample Preparation

For chemical analysis, all samples were wet sieved with the > 2 mm size fraction being removed using plastic sieves and ultra pure water. The < 2 mm portion, along with all washings, was dried at 50°C in a stainless steel forced draft oven. Samples were subsequently ground to < 50 μm particle size using a 'shatter box' grinding mill equipped with a stabilised zirconium grinding head.

Chemical Analysis

For Al, Ca, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Si and Zn determination samples were pelleted using the pressed powder technique and analysed by X-ray fluorescence. For As and Se determination samples were digested using nitric:perchloric:sulphuric acid (13:1:2) and analysed by hydride generation atomic absorption spectrometry. Cadmium and Hg determinations were performed on solutions obtained from a nitric:hydrochloric acid (6:2) digest following two hours on a steam bath. Cadmium was analysed by graphite furnace AAS, while Hg was determined by hydride generation AAS. Organic carbon was determined by the wet oxidation method of Walkley and Black (1934). Calcium carbonate was determined by a weight loss gravimetric method following a procedure outlined by Blakemore et al (1987).

Reporting limits were as follows (units are in mg/kg unless otherwise indicated):

Al 0.01%, As 1, Ca 0.01%, Cd 0.01, Co 1, Cr 1, Cu 1, Fe 0.01%, Hg 0.005, Mg 0.01%, Mn 1, Ni 1, Pb 1, Se 0.04, Si 0.01%, Zn 1; Particle Size Analysis 1%, Organic carbon 0.1%, Calcium carbonate 1%.

Physical Analysis

A sub-sample was wet sieved and separated into four particle size fractions as follows: > 2 mm, 2-0.2 mm, 0.2-0.063 mm, < 0.063 mm.

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A comparison of sediment arsenic concentrations (mg/kg) in the monsoon season determined by different methods. Preliminary values were determined by X-ray fluorescence and amended values were determined by atomic absorption spectrometry (see Methods and Materials section in text). Preliminary arsenic (As) values were used in statistical analysis for this report. SD = standard deviation. Unless stated otherwise, mean values shown in this report are arithmetic means.

Sample	Preliminary As value	Amended As value	Sample	Preliminary As value	Amended As value
S1/10	12	17	S5/10	7	14
S1/11	10	16	S5/11	6	14
S1/12	12	16	S5/12	5	11
S1/13	12	15	S5/13	11	17
S1/14	11	15	S5/14	6	14
S1/15	12	16	S5/15	9	17
S1/16	9	15	S5/16	7	14
S1/17	12	16	S5/17	8	14
S1/18	10	13	S5/18	7	14
Mean	11.11	15.44	Mean	7.33	14.33
SD	1.167	1.13	SD	1.803	1.803
S6/10	14	22	S7/10	7	14
S6/11	15	22	S7/11	8	15
S6/12	16	24	S7/12	8	14
S6/13	25	40	S7/13	11	19
S6/14	24	38	S7/14	8	18
S6/15	26	42	S7/15	9	16
S6/16	27	46	S7/16	9	15
S6/17	29	47	S7/17	7	14
S6/18	31	56	S7/18	7	15
Mean	23.00	37.44	Mean	8.22	15.56
SD	6.364	12.218	SD	1.302	1.810
S8/10	34	56	S10/10	19	25
S8/11	43	67	S10/11	16	21
S8/12	32	48	S10/12	17	21
S8/13	46	82	S10/13	15	19
S8/14	34	56	S10/14	14	19
S8/15	47	78	S10/15	13	19
S8/16	48	75	S10/16	21	35
S8/17	47	79	S10/17	26	37
S8/18	53	90	S10/18	25	37
Mean	42.67	70.11	Mean	18.44	25.89
SD	7.483	14.137	SD	4.693	8.069

Sample	Preliminary As value	Amended As value	Sample	Preliminary As value	Amended As value
S11/10	36	61	S12/10	23	35
S11/11	45	68	S12/11	15	21
S11/12	41	62	S12/12	8	12
S11/13	32	52	S12/13	33	49
S11/14	37	58	S12/14	37	57
S11/15	41	63	S12/15	32	49
S11/16	43	65	S12/16	24	36
S11/17	43	68	S12/17	24	33
S11/18	43	66	S12/18	25	36
Mean	40.11	62.56	Mean	24.56	36.44
SD	4.226	5.151	SD	9.015	14.090
S13/10	21	30	S14/10	2	7
S13/11	19	27	S14/11	3	9
S13/12	26	41	S14/12	3	7
S13/13	18	27	S14/13	4	8
S13/14	18	29	S14/14	6	11
S13/15	19	31	S14/15	6	11
S13/16	28	42	S14/16	5	9
S13/17	27	42	S14/17	6	13
S13/18	24	38	S14/18	4	10
Mean	22.22	34.11	Mean	4.33	9.44
SD	4.055	6.528	SD	1.500	2.007
S15/10	25	28	S16/10	4	7
S15/11	23	34	S16/11	3	7
S15/12	25	38	S16/12	2	7
S15/13	32	46	S16/13	1	5
S15/14	34	46	S16/14	2	5
S15/15	29	41	S16/15	2	5
S15/16	33	49	S16/16	2	6
S15/17	34	51	S16/17	2	5
S15/18	30	42	S16/18	3	6
Mean	29.44	41.67	Mean	2.33	5.89
SD	4.216	7.399	SD	0.866	0.928
S17/10	8	17	S18/10	24	36
S17/11	9	16	S18/11	24	37
S17/12	10	18	S18/12	24	41
S17/13	9	16	S18/13	29	45
S17/14	9	17	S18/14	27	38
S17/15	12	18	S18/15	27	40
S17/16	9	16	S18/16	31	48
S17/17	11	20	S18/17	34	54
S17/18	10	18	S18/18	28	44
Mean	9.67	17.33	Mean	27.56	42.56
SD	1.225	1.323	SD	3.432	5.833

Physical and chemical properties of sediment samples collected in the Torres Strait in pre-monsoon (PM) and monsoon (M) seasons. Locations of stations are shown in figure 1.1. Values shown for particle size distribution are precentages of total sample weight. Ca = calcium; Si = silicon; Org C = organic carbon; $CaCO_3$ = calcium carbonate. Mean value for each station is based on pooled data from three sites and three replicates per site (i.e. a total of nine replicate samples); SD = standard deviation.

			Particle Size Distribution							
Station	Season	Value	> 2.0 mm	2.0-0.2 mm	0.2-.063 mm	< 0.063 mm	Ca %	Si %	Org C %	$CaCO_3$ %
S1	PM	Mean	0	1	61	38	0.97	29.82	0.8	1
		SD	0	0	9	9	0.083	0.433	0.1	0.5
		Max	1	1	71	58	1.15	30.47	1.0	2
		Min	0	1	40	29	0.89	29.08	0.8	1
	M	Mean	0	3	42	55	0.73	28.76	1.1	< 1
		SD		2	12	13	0.037	0.280	0.1	
		Max		6	63	70	0.78	29.09	1.2	
		Min		1	26	33	0.68	28.21	1.0	
S5	PM	Mean	14	43	22	20	31.86	4.99	0.7	77
		SD	5	3	4	3	0.617	0.165	0	2
		Max	20	48	27	22	32.48	5.26	0.7	79
		Min	7	40	17	15	30.74	4.79	0.7	75
	M	Mean	15	46	19	20	31.64	3.84	0.7	74
		SD	4	2	2	2	0.132	0.138	0	17
		Max	22	49	22	24	31.80	4.13	0.8	86
		Min	9	43	15	18	31.39	3.70	0.7	31
S6	PM	Mean	18	52	15	15	23.18	11.41	0.7	51
		SD	12	8	3	4	0.702	0.617	0.2	2
		Max	37	60	18	20	24.11	12.32	1.0	54
		Min	8	41	9	10	21.85	10.55	0.4	48
	M	Mean	11	53	19	16	20.68	12.06	0.6	49
		SD	3	5	3	4	0.895	1.009	0.1	4
		Max	18	58	24	24	21.44	13.94	0.7	54
		Min	8	45	15	12	18.84	11.07	0.5	40
S7	PM	Mean	30	54	4	12	34.14	3.81	0.7	80
		SD	6	6	1	2	0.621	0.261	0	4
		Max	41	64	5	15	34.90	4.25	0.7	86
		Min	24	43	3	9	33.14	3.45	0.6	76
	M	Mean	27	55	7	12	32.90	2.56	0.6	84
		SD	7	8	1	5	1.075	0.123	0.1	6
		Max	37	64	8	25	33.55	2.83	0.7	91
		Min	18	40	5	7	30.08	2.44	0.6	72

			Particle Size Distribution							
Station	Season	Value	> 2.0 mm	2.0-0.2 mm	0.2-.063 mm	< 0.063 mm	Ca %	Si %	Org C %	$CaCO_3$ %
S8	PM	Mean	27	50	6	16	18.63	13.94	0.9	42
		SD	15	14	2	9	5.246	4.126	0.2	15
		Max	49	78	8	35	29.39	19.83	1.2	75
		Min	6	30	1	8	11.81	5.32	0.5	23
	M	Mean	31	50	6	12	17.42	13.68	0.8	42
		SD	11	10	3	6	5.474	4.169	0.2	16
		Max	50	71	10	18	27.47	18.06	1.1	70
		Min	16	35	2	2	12.30	6.18	0.5	27
S10	PM	Mean	1	9	74	17	12.90	19.45	0.5	27
		SD	0	3	3	2	0.599	0.616	0.1	1
		Max	1	14	78	19	13.66	20.30	0.5	30
		Min	0	4	69	13	12.17	18.75	0.4	26
	M	Mean	2	15	71	11	14.55	17.48	0.5	30
		SD	1	2	5	4	0.445	0.479	0	4
		Max	4	18	77	18	15.21	18.26	0.5	36
		Min	1	11	63	6	13.85	16.91	0.4	24
S11	PM	Mean	39	31	13	17	15.55	14.67	0.5	38
		SD	4	2	1.5	2	0.451	0.638	0.	1
		Max	44	34	15	20	16.25	15.78	0.5	40
		Min	32	28	10	14	14.80	13.55	0.5	37
	M	Mean	39	28	15	18	17.10	14.70	0.6	39
		SD	11	5	3	5	0.948	0.624	0	3
		Max	55	35	19	24	18.08	15.77	0.6	43
		Min	25	23	11	9	15.74	13.85	0.6	33
S12	PM	Mean	29	23	11	37	10.43	19.80	0.7	21
		SD	11	6	2	14	0.640	2.733	0.1	4
		Max	47	34	14	55	11.27	22.70	0.9	26
		Min	15	16	9	17	9.39	15.89	0.6	16
	M	Mean	57	15	10	18	15.87	16.37	0.8	35
		SD	6	4	2	5	2.388	1.774	0.1	6
		Max	64	20	12	27	18.72	18.72	1.1	44
		Min	47	9	6	8	12.20	14.24	0.6	25

			Particle Size Distribution							
Station	Season	Value	> 2.0 mm	2.0-0.2 mm	0.2-.063 mm	< 0.063 mm	Ca %	Si %	Org C %	$CaCO_3$ %
S13	PM	Mean	33	31	17	19	11.67	18.39	0.7	26
		SD	16	11	3	11	0.527	1.458	0.2	3
		Max	62	57	24	41	12.51	20.22	1.0	31
		Min	10	21	13	2	10.53	15.23	0.4	22
	M	Mean	38	30	13	18	15.10	17.18	0.6	33
		SD	25	14	8	9	3.293	2.295	0.1	9
		Max	83	53	22	36	20.48	21.44	0.8	50
		Min	15	10	2	5	9.62	13.71	0.4	19
S14	PM	Mean	16	60	7	17	32.10	4.98	0.4	80
		SD	6	9	2	5	0.446	0.363	0	1
		Max	23	76	10	24	32.72	5.52	0.4	82
		Min	9	52	5	10	31.48	4.51	0.3	77
	M	Mean	18	57	9	16	32.43	3.69	0.6	81
		SD	8	8	1	2	0.568	0.303	01	5
		Max	32	65	11	21	32.92	4.26	0.6	86
		Min	11	42	7	14	31.11	3.36	0.5	73
S15	PM	Mean	4	45	35	16	14.99	17.65	0.5	30
		SD	2	4	3	4	0.875	0.843	0.1	2
		Max	8	51	40	23	16.22	19.65	0.6	33
		Min	1	35	30	10	12.95	16.82	0.4	28
	M	Mean	5	47	36	11	13.79	17.36	0.5	31
		SD	2	2	3	2	0.962	0.758	0	5
		Max	11	51	40	15	15.04	18.65	0.6	40
		Min	3	44	32	9	12.10	16.48	0.5	24
S16	PM	Mean	7	43	21	29	29.57	7.34	0.6	70
		SD	2	3	1	2	0.727	0.395	0.1	3
		Max	10	50	23	31	31.12	7.81	0.7	76
		Min	5	39	18	24	28.75	6.62	0.5	67
	M	Mean	8	45	22	26	28.91	6.48	0.7	67
		SD	1	3	1	2	0.281	0.251	0	5
		Max	9	51	24	29	29.49	6.89	0.7	72
		Min	6	42	20	23	28.59	6.00	0.7	56

Particle Size Distribution										
Station	Season	Value	> 2.0 mm	2.0-0.2 mm	0.2-.063 mm	< 0.063 mm	Ca %	Si %	Org C %	$CaCO_3$ %
S17	PM	Mean	19	49	7	24	32.07	5.40	0.5	79
		SD	6	4	2	5	0.422	0.227	0	2
		Max	34	55	9	33	32.48	5.75	0.6	82
		Min	14	43	4	16	31.06	5.09	0.5	76
	M	Mean	21	49	7	23	31.33	4.34	0.7	74
		SD	6	5	1	3	0.222	0.190	0	5
		Max	36	54	8	26	31.66	4.72	0.7	79
		Min	15	40	6	18	31.12	4.13	0.6	62
S18	PM	Mean	10	56	19	15	22.63	9.69	0.6	56
		SD	4	10	5	4	1.400	1.543	0.1	6
		Max	18	80	24	19	26.12	11.76	0.7	70
		Min	5	48	9	5	21.46	6.61	0.5	49
	M	Mean	8	50	28	14	23.74	9.82	0.4	57
		SD	3	5	6	2	0.332	0.363	0	2
		Max	12	56	37	17	24.26	10.46	0.5	60
		Min	4	42	22	12	23.31	9.31	0.4	54

Summary of the levels of trace metal and other elements (in mg/kg or % where indicated) in sediments collected in the Torres Strait in the pre-monsoon and monsoon seasons. Locations of stations are shown in figure 1.1. Values shown are mean (nine replicates pooled), standard deviation (SD) and range (max, min).

STATION S1

SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	7.24	0.272	7.76	6.83	8.66	0.111	8.84	8.48
As	18	2	21	16	11	1	12	9
Cd	0.01	0.003	0.02	0.01	0.02	0.000	0.02	0.02
Co	15	1	17	14	19	1	20	18
Cr	82	3	86	77	86	3	88	79
Cu	18	2	22	14	23	3	27	18
Fe%	4.61	0.081	4.74	4.52	5.03	0.103	5.10	4.84
Hg	0.08	0.011	0.10	0.07	0.04	0.003	0.05	0.04
Mg%	0.73	0.035	0.78	0.67	1.27	0.013	1.29	1.25
Mn	638	25	668	598	636	20	680	612
Ni	40	2	44	36	41	1	43	39
Pb	15	1	17	13	20	2	23	16
Se	0.16	0.049	0.20	0.10	0.11	0.014	0.13	0.10
Zn	95	2	98	93	95	2	97	92

STATION S5

SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	0.61	0.046	0.68	0.55	1.01	0.058	1.12	0.90
As	14	3	17	9	7	2	11	5
Cd	0.03	0.005	0.04	0.03	0.03	0.003	0.04	0.03
Co	4	1	5	4	1	0	2	1
Cr	19	2	24	17	33	3	40	29
Cu	4	1	5	3	3	1	6	1
Fe%	1.82	0.297	2.46	1.31	1.63	0.219	1.94	1.21
Hg	0.03	0.000	0.03	0.03	0.01	0.004	0.02	0.01
Mg%	1.86	0.045	1.95	1.78	1.75	0.042	1.84	1.70
Mn	228	17	258	203	198	12	214	179
Ni	8	1	10	6	4	2	7	1
Pb	7	1	8	5	10	1	11	7
Se	0.21	0.033	0.30	0.20	0.12	0.022	0.14	0.07
Zn	9	1	11	9	11	1	13	9

STATION	S6							
SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	2.54	0.179	2.83	2.24	3.37	0.503	4.13	2.29
As	47	5	55	40	23	6	31	14
Cd	0.03	0.005	0.03	0.02	0.03	0.003	0.04	0.03
Co	9	1	10	8	11	2	14	8
Cr	39	3	42	35	55	3	62	50
Cu	6	1	8	5	7	1	9	5
Fe%	4.42	0.334	4.97	3.99	4.12	0.443	4.64	3.50
Hg	0.04	0.023	0.09	0.03	0.02	0.006	0.03	0.01
Mg%	2.05	0.080	2.20	1.95	2.25	0.134	2.38	2.03
Mn	468	32	521	409	421	46	463	357
Ni	19	2	21	16	19	2	23	16
Pb	12	1	14	10	15	2	21	13
Se	0.22	0.044	0.30	0.20	0.13	0.013	0.15	0.11
Zn	36	2	38	32	44	2	46	41
STATION	S7							
SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	0.40	0.047	0.47	0.33	0.73	0.052	0.85	0.67
As	17	4	23	12	8	1	11	7
Cd	0.08	0.009	0.09	0.07	0.04	0.003	0.05	0.04
Co	3	1	5	2	1	0	1	1
Cr	14	3	20	11	25	1	27	22
Cu	3	1	4	2	4	1	6	3
Fe%	0.92	0.208	1.16	0.66	0.92	0.059	1.05	0.86
Hg	0.03	0.000	0.03	0.03	0.01	0.004	0.02	0.01
Mg%	1.94	0.052	2.01	1.86	1.81	0.038	1.86	1.76
Mn	205	43	275	148	218	14	239	195
Ni	7	1	8	5	5	1	6	3
Pb	4	2	7	2	9	3	14	5
Se	0.24	0.046	0.30	0.20	0.14	0.014	0.18	0.13
Zn	8	1	9	7	12	1	13	10
STATION	S8							
SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	3.42	1.253	4.99	0.77	4.22	1.210	5.50	1.91
As	73	15	90	55	43	7	53	32
Cd	0.04	0.004	0.04	0.03	0.04	0.007	0.05	0.03
Co	12	3	14	6	19	7	27	9
Cr	55	16	72	21	76	21	99	44
Cu	11	2	13	6	9	3	13	5
Fe%	5.40	1.495	7.33	3.27	6.02	1.491	7.94	3.96
Hg	0.03	0.008	0.05	0.03	0.03	0.006	0.04	0.02
Mg%	1.66	0.169	1.93	1.38	1.75	0.099	1.88	1.58
Mn	1206	351	1986	867	360	328	884	122
Ni	25	7	37	13	23	6	28	12
Pb	17	1	19	15	21	2	25	16
Se	0.28	0.046	0.35	0.20	0.19	0.038	0.24	0.12
Zn	50	13	66	21	57	12	67	35

STATION S10								
SEASON	**Pre-monsoon**				**Monsoon**			
VALUE	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Al%	2.94	0.152	3.18	2.74	3.87	0.184	4.10	3.58
As	25	4	33	19	18	5	26	13
Cd	0.02	0.000	0.02	0.02	0.03	0.007	0.04	0.02
Co	9	1	11	8	13	2	15	11
Cr	74	6	82	68	91	7	104	83
Cu	8	1	9	6	9	1	12	7
Fe%	3.50	0.187	3.73	3.24	3.94	0.416	4.54	3.54
Hg	0.03	0.000	0.03	0.03	0.02	0.003	0.02	0.02
Mg%	1.35	0.062	1.43	1.27	1.75	0.051	1.82	1.68
Mn	396	21	425	361	437	39	499	390
Ni	22	2	25	20	24	1	25	22
Pb	12	1	13	10	16	3	22	13
Se	0.23	0.067	0.40	0.20	0.11	0.008	0.12	0.10
Zn	45	2	48	42	52	2	55	49
STATION	**S11**							
SEASON	**Pre-monsoon**				**Monsoon**			
VALUE	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Al%	3.07	0.146	3.25	2.81	3.97	0.253	4.36	3.65
As	91	10	104	68	40	4	45	32
Cd	0.05	0.009	0.06	0.04	0.04	0.006	0.05	0.03
Co	12	2	14	9	14	1	17	13
Cr	50	2	53	47	65	4	72	59
Cu	9	3	17	7	8	1	10	6
Fe%	5.22	0.669	6.21	4.33	4.86	0.262	5.12	4.37
Hg	0.05	0.017	0.08	0.03	0.04	0.011	0.06	0.03
Mg%	1.79	0.099	1.93	1.64	1.82	0.085	1.98	1.74
Mn	681	53	786	595	612	37	666	535
Ni	23	2	25	20	20	1	22	18
Pb	17	1	19	15	19	3	22	14
Se	0.26	0.039	0.30	0.20	0.12	0.005	0.13	0.12
Zn	41	3	49	39	46	2	49	44
STATION	**S12**							
SEASON	**Pre-monsoon**				**Monsoon**			
VALUE	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Al%	4.75	0.809	5.65	3.69	4.60	0.745	5.69	3.74
As	55	26	96	30	25	9	37	8
Cd	0.03	0.005	0.04	0.03	0.04	0.003	0.05	0.04
Co	13	2	17	11	12	2	15	7
Cr	75	3	79	71	67	3	70	63
Cu	11	2	14	8	11	3	16	8
Fe%	5.80	1.828	8.53	4.15	3.82	0.541	4.32	2.65
Hg	0.05	0.016	0.06	0.03	0.03	0.007	0.04	0.02
Mg%	1.14	0.177	1.37	0.91	1.48	0.132	1.70	1.34
Mn	545	202	844	340	669	151	876	413
Ni	28	3	36	24	23	2	27	20
Pb	16	2	18	13	16	2	19	12
Se	0.29	0.068	0.40	0.20	0.18	0.098	0.43	0.11
Zn	56	5	65	50	50	5	57	45

STATION	S13							
SEASON	**Pre-monsoon**				**Monsoon**			
VALUE	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Al%	3.88	0.567	4.63	2.67	5.00	0.851	6.45	3.85
As	49	16	83	29	22	4	28	17
Cd	0.04	0.007	0.05	0.03	0.04	0.018	0.08	0.03
Co	12	1	14	10	15	3	19	10
Cr	91	16	127	73	87	20	114	59
Cu	11	2	13	8	12	4	23	10
Fe%	5.37	0.911	7.37	4.30	4.63	0.856	5.63	3.04
Hg	0.06	0.014	0.07	0.03	0.03	0.003	0.03	0.03
Mg%	1.34	0.036	1.42	1.30	1.44	0.187	1.60	1.02
Mn	626	136	940	466	677	122	926	514
Ni	29	2	34	26	26	4	31	20
Pb	16	2	19	14	19	2	22	15
Se	0.30	0.035	0.35	0.25	0.15	0.041	0.23	0.08
Zn	57	2	62	55	60	7	68	48

STATION	S14							
SEASON	**Pre-monsoon**				**Monsoon**			
VALUE	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Al%	0.59	0.085	0.70	0.41	1.00	0.113	1.18	0.87
As	20	10	34	8	4	1	6	2
Cd	0.04	0.004	0.05	0.04	0.03	0.003	0.04	0.03
Co	4	1	5	3	1	0	1	1
Cr	19	4	24	12	25	2	29	22
Cu	4	1	5	3	4	1	6	3
Fe%	1.12	0.433	1.67	0.64	0.77	0.106	0.87	0.63
Hg	0.03	0.000	0.03	0.03	0.01	0.003	0.02	0.01
Mg%	1.92	0.137	2.11	1.75	1.73	0.027	1.77	1.68
Mn	254	141	454	116	131	15	148	112
Ni	8	2	11	5	5	2	8	2
Pb	5	2	9	2	9	2	11	5
Sc	0.27	0.094	0.35	0.15	0.15	0.017	0.19	0.13
Zn	13	2	15	9	14	1	15	12

STATION	S15							
SEASON	**Pre-monsoon**				**Monsoon**			
VALUE	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Al%	3.78	0.275	4.25	3.41	4.84	0.287	5.32	4.45
As	43	8	52	30	29	4	34	23
Cd	0.02	0.003	0.03	0.02	0.02	0.000	0.02	0.02
Co	11	1	13	9	17	2	20	14
Cr	89	13	102	70	109	8	121	98
Cu	8	1	9	7	8	1	10	6
Fe%	4.82	0.327	5.32	4.35	5.28	0.357	5.75	4.72
Hg	0.03	0.011	0.05	0.03	0.02	0.002	0.02	0.02
Mg%	1.74	0.097	1.88	1.53	2.23	0.058	2.33	2.17
Mn	534	48	594	466	583	54	650	505
Ni	30	2	33	28	34	2	39	32
Pb	12	1	14	10	15	1	17	13
Se	0.19	0.030	0.25	0.15	0.12	0.007	0.13	0.11
Zn	54	3	58	50	60	3	63	55

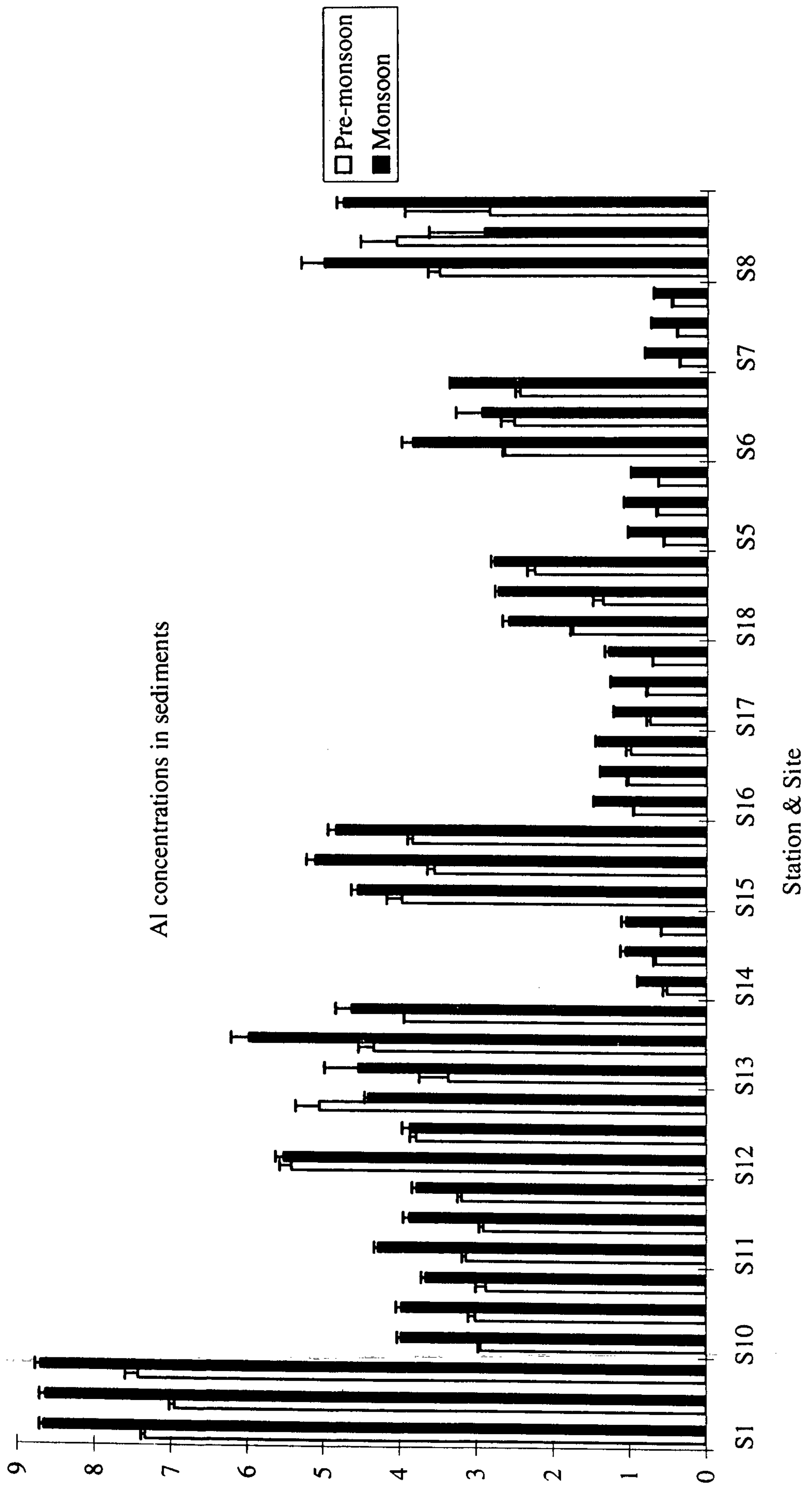
STATION	S16							
SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	0.99	0.070	1.11	0.89	1.42	0.065	1.50	1.30
As	7	1	9	6	2	1	4	1
Cd	0.02	0.000	0.02	0.02	0.02	0.000	0.02	0.02
Co	4	1	5	3	1	0.5	2	1
Cr	25	2	29	23	36	4	41	32
Cu	4	0.5	4	3	4	1	5	2
Fe%	1.42	0.141	1.70	1.27	1.37	0.170	1.58	1.14
Hg	0.03	0.000	0.03	0.03	0.02	0.004	0.02	0.01
Mg%	2.09	0.063	2.22	2.02	2.13	0.034	2.20	2.10
Mn	246	25	278	212	229	37	276	180
Ni	10	1	11	8	8	1	9	7
Pb	6	2	8	4	9	2	12	6
Se	0.19	0.033	0.25	0.15	0.12	0.005	0.12	0.11
Zn	15	1	17	14	18	1	19	16

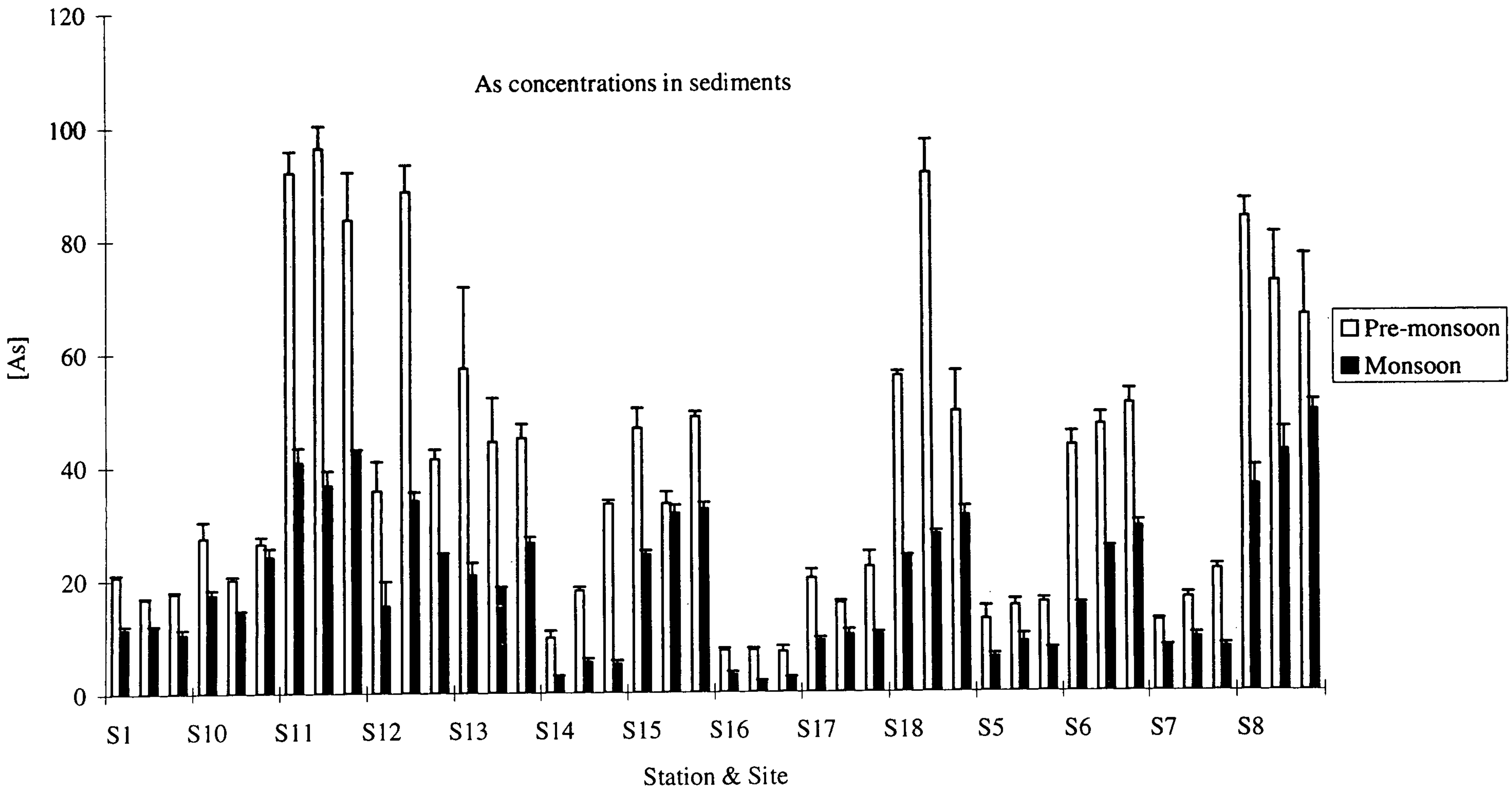
STATION	S17							
SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	0.74	0.052	0.83	0.69	1.25	0.056	1.36	1.19
As	19	4	26	15	10	1	12	8
Cd	0.04	0.010	0.06	0.03	0.03	0.005	0.04	0.03
Co	4	1	5	3	1	0.3	2	1
Cr	20	1	22	18	30	1	32	27
Cu	4	0.4	4	3	3	1	6	2
Fe%	1.77	0.173	1.95	1.41	1.64	0.146	1.84	1.42
Hg	0.03	0.000	0.03	0.03	0.02	0.007	0.03	0.01
Mg%	1.95	0.023	1.98	1.91	1.86	0.028	1.91	1.83
Mn	190	13	209	168	168	11	187	153
Ni	9	0.5	10	8	7	2	11	4
Pb	6	2	9	3	10	1	11	8
Se	0.22	0.036	0.30	0.20	0.14	0.012	0.16	0.13
Zn	15	2	17	12	19	1	20	17

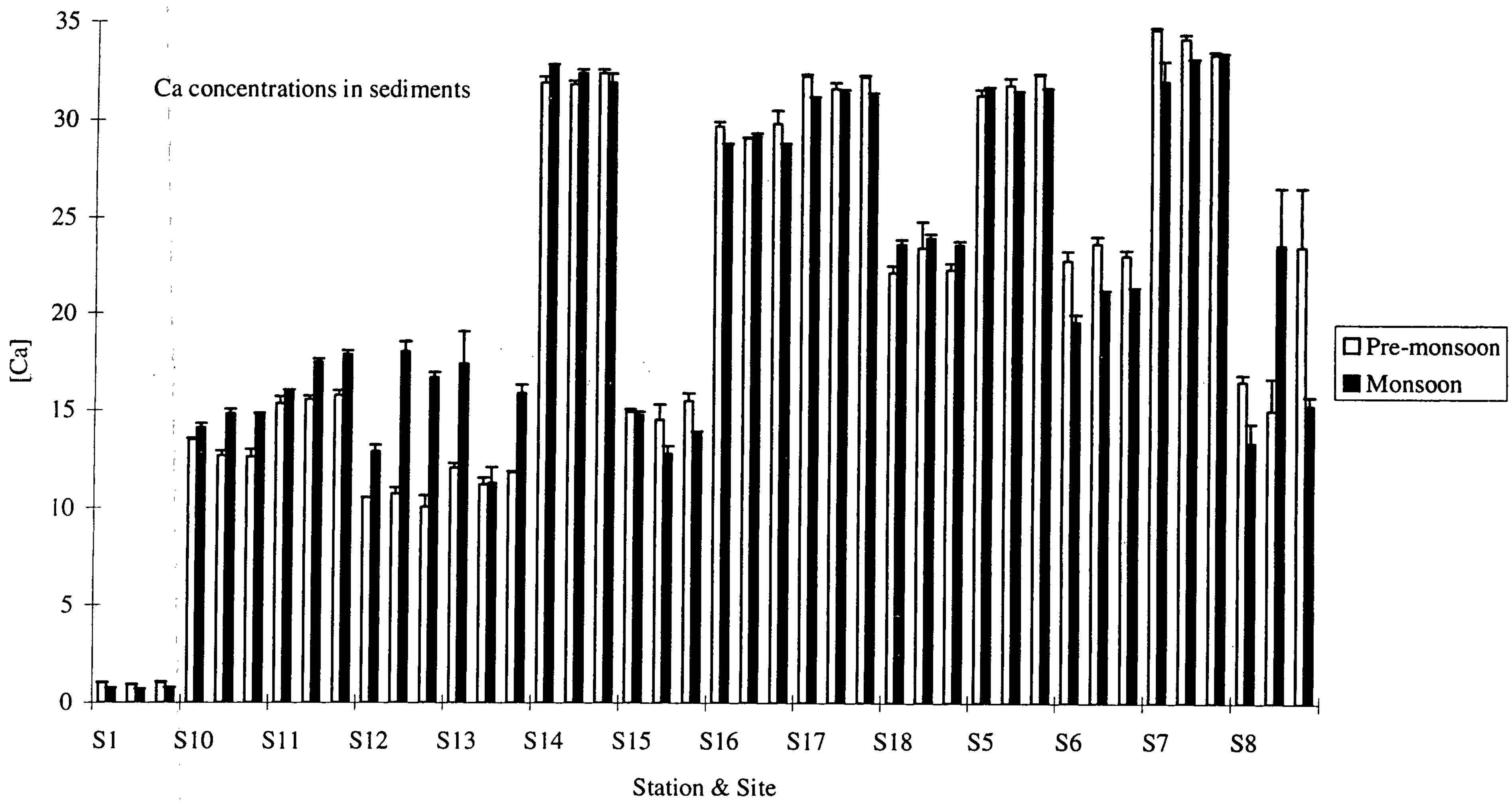
STATION	S18							
SEASON	Pre-monsoon				Monsoon			
VALUE	Mean	SD	Max	Min	Mean	SD	Max	Min
Al%	1.79	0.414	2.45	1.09	2.69	0.122	2.82	2.45
As	66	21	102	35	28	3	34	24
Cd	0.04	0.005	0.04	0.03	0.04	0.005	0.04	0.03
Co	9	1	12	8	8	1	10	6
Cr	47	8	58	33	60	3	64	55
Cu	6	1	8	5	6	1	8	5
Fe%	4.78	0.704	5.85	4.12	3.51	0.394	4.05	3.03
Hg	0.03	0.000	0.03	0.03	0.02	0.003	0.02	0.01
Mg%	2.12	0.103	2.37	2.02	2.14	0.133	2.30	1.97
Mn	625	115	883	514	537	41	586	476
Ni	17	1	19	15	14	2	17	12
Pb	16	10	18	12	17	2	19	14
Se	0.16	0.042	0.25	0.10	0.09	0.005	0.10	0.09
Zn	29	5	36	19	33	2	35	30

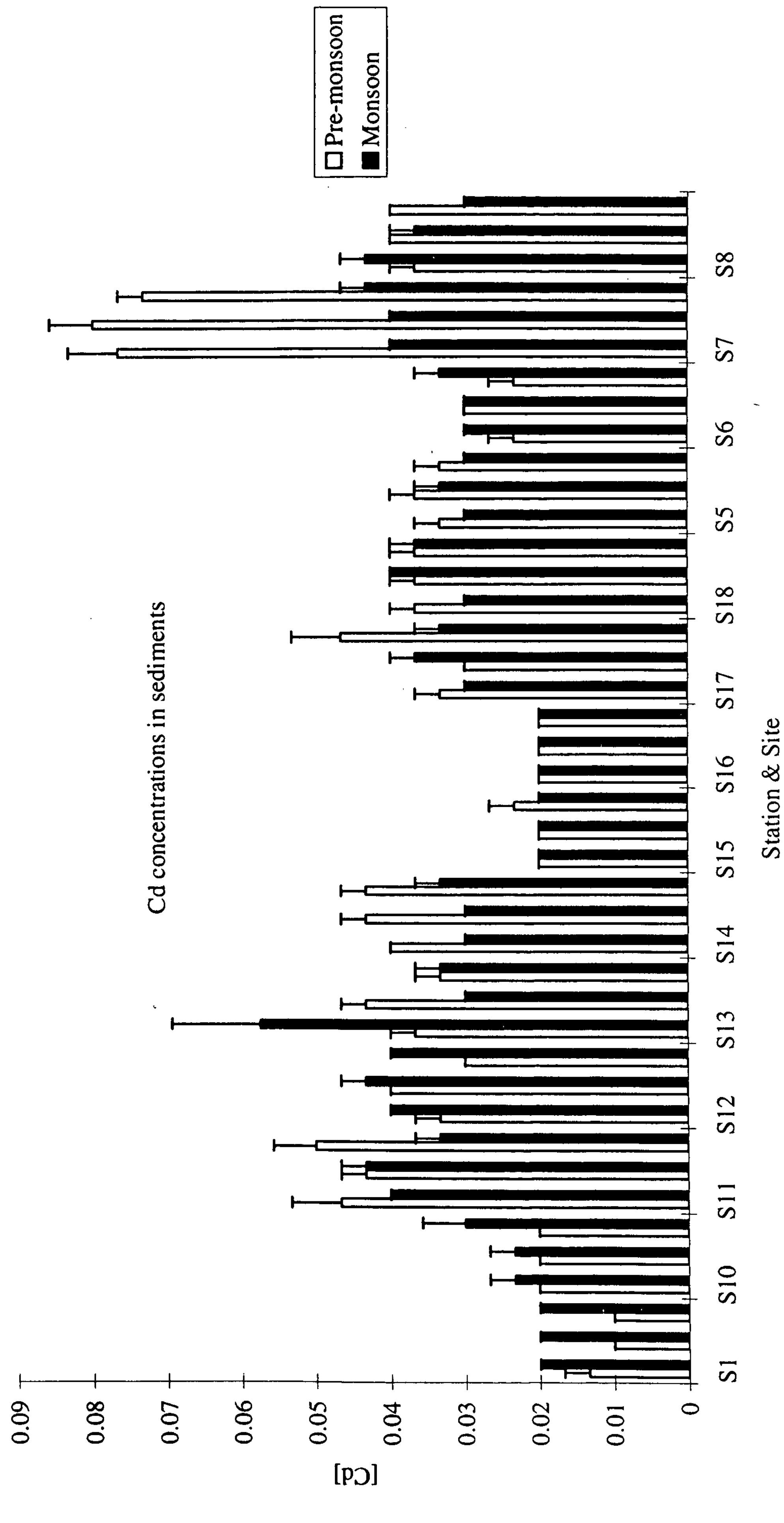
APPENDIX 5 (on following pages)

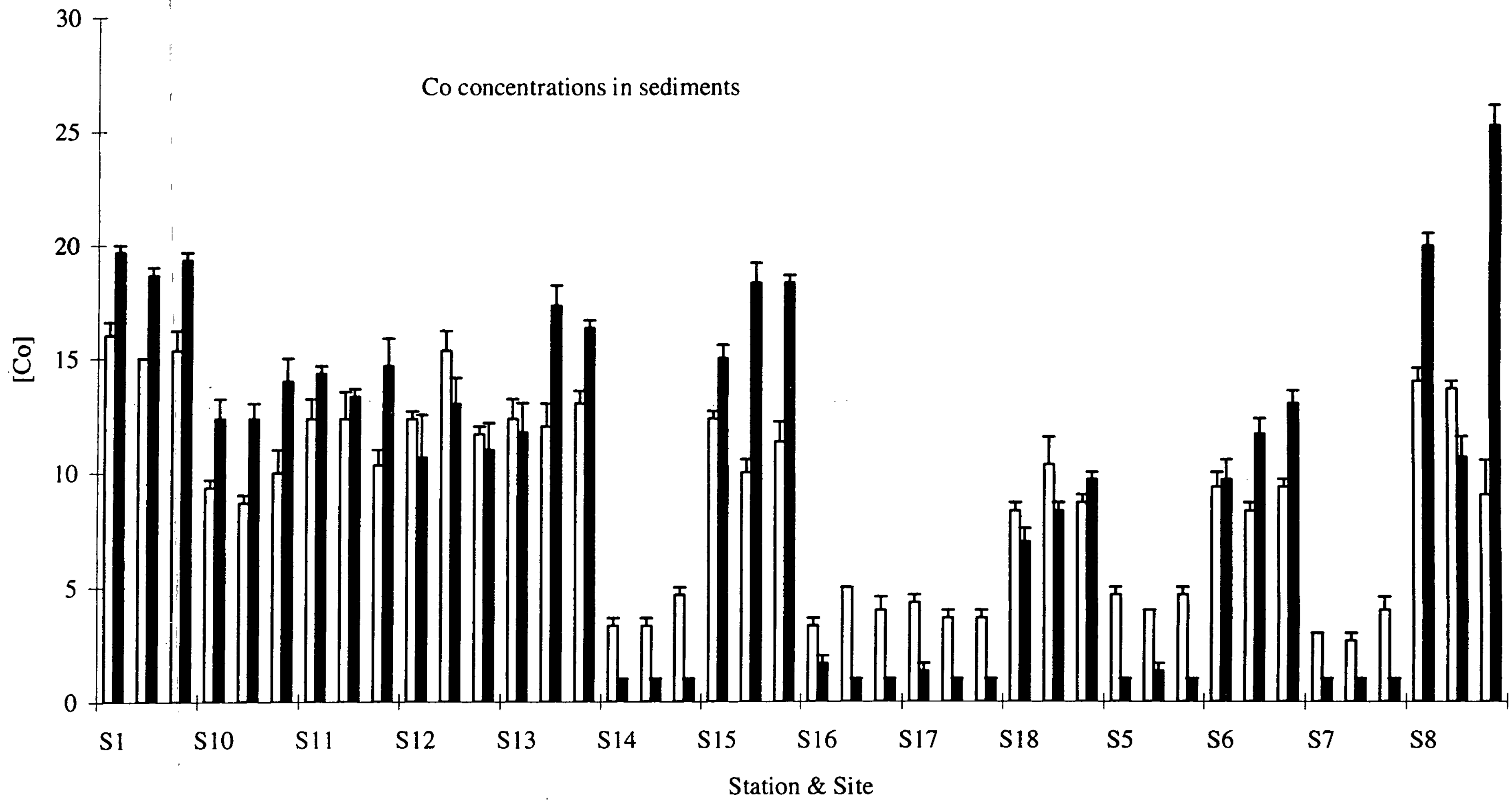
Trace metal and element concentrations (in mg/kg) in Torres Strait sediments in pre-monsoon and monsoon seasons. Means and standard errors are shown for each site in each station; N = 3 replicates at each site. Locations of stations are shown in figure 1.1.


Al concentrations in sediments
Pre-monsoon
Monsoon
[Al]
0
1
2
3
4
5
6
7
8
9
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site

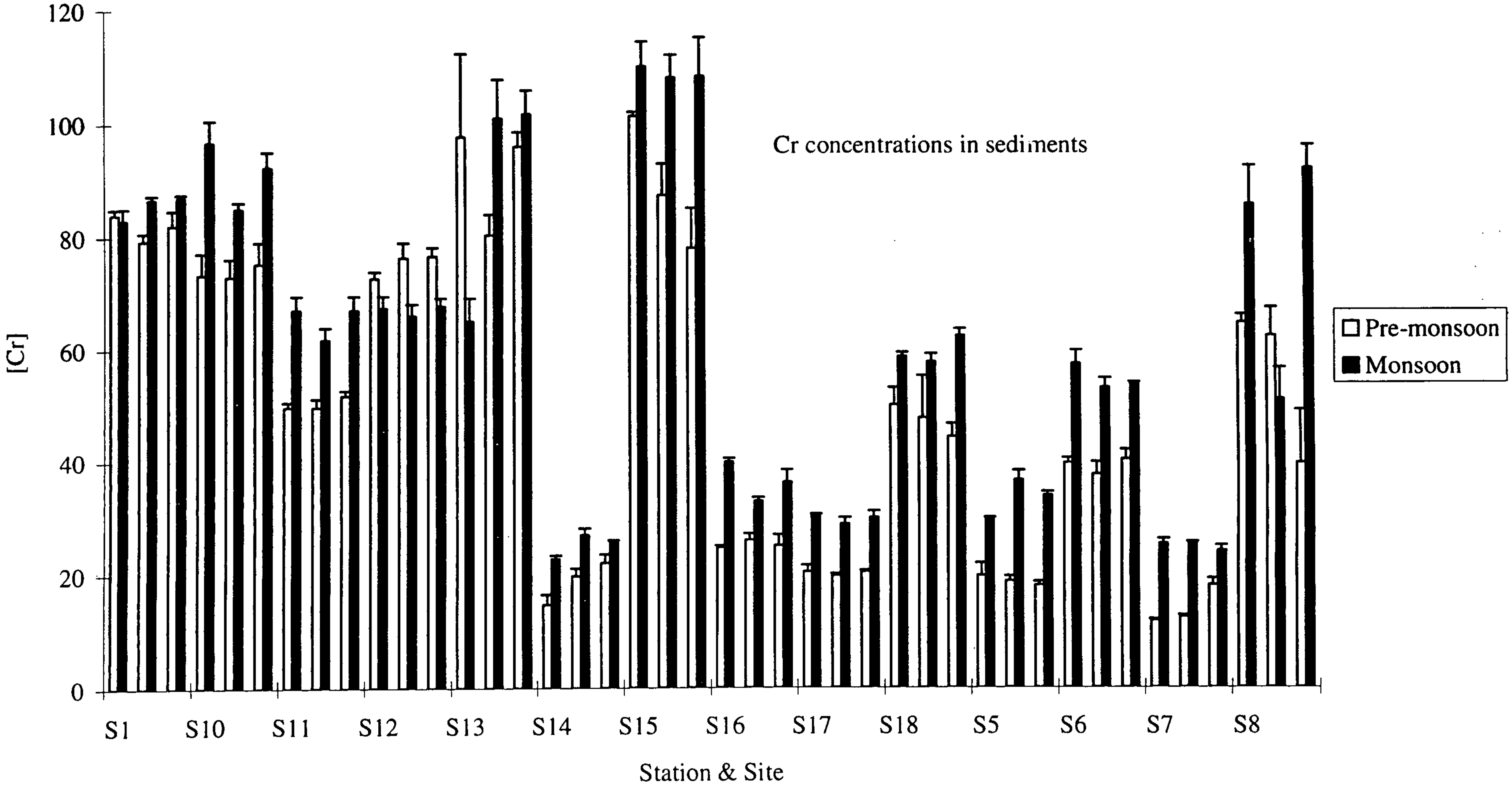

As concentrations in sediments
[As]
120
100
80
60
40
20
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon


Ca concentrations in sediments
[Ca]
35
30
25
20
15
10
5
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon

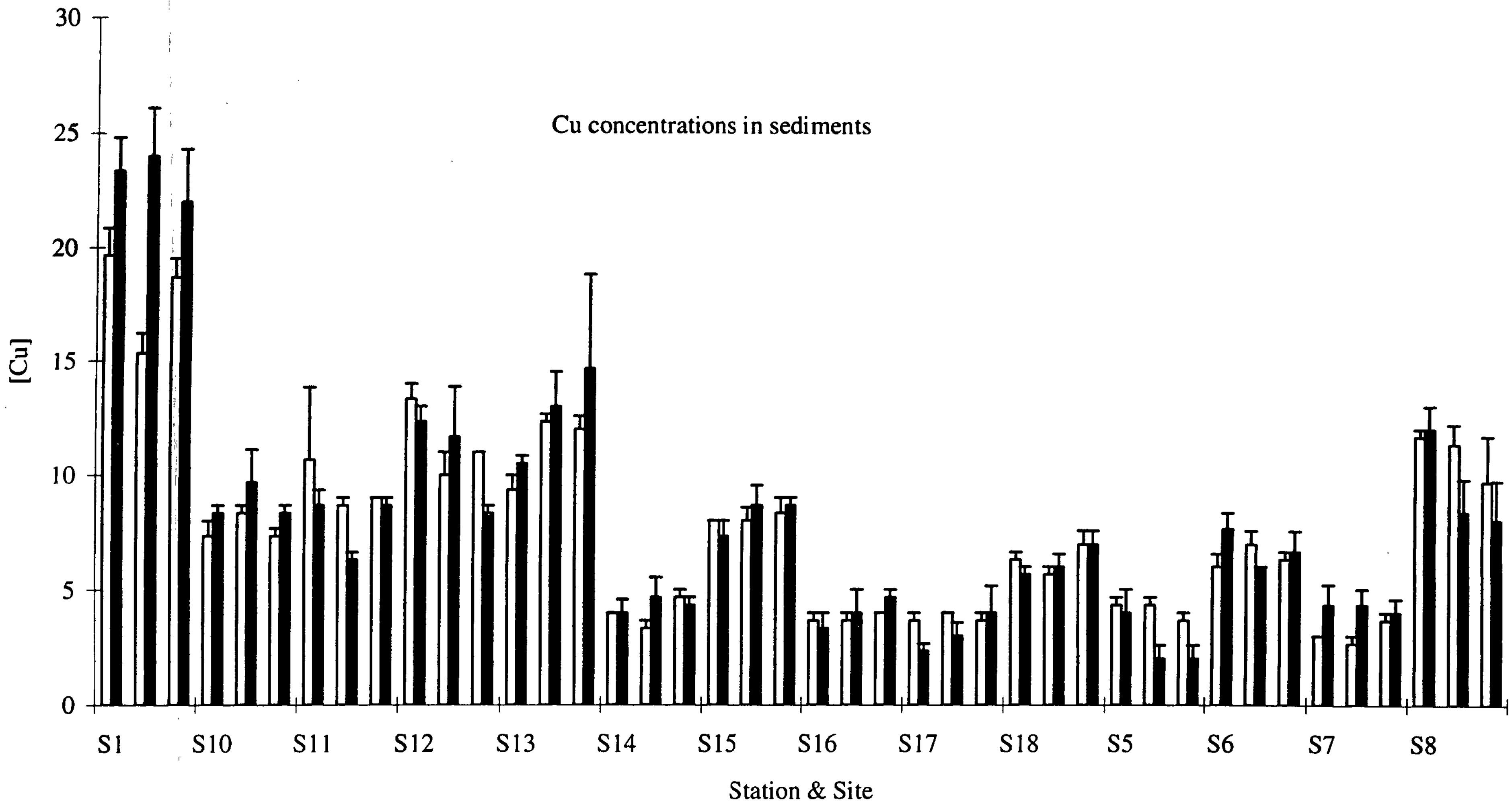

Cd concentrations in sediments
[Cd]
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon

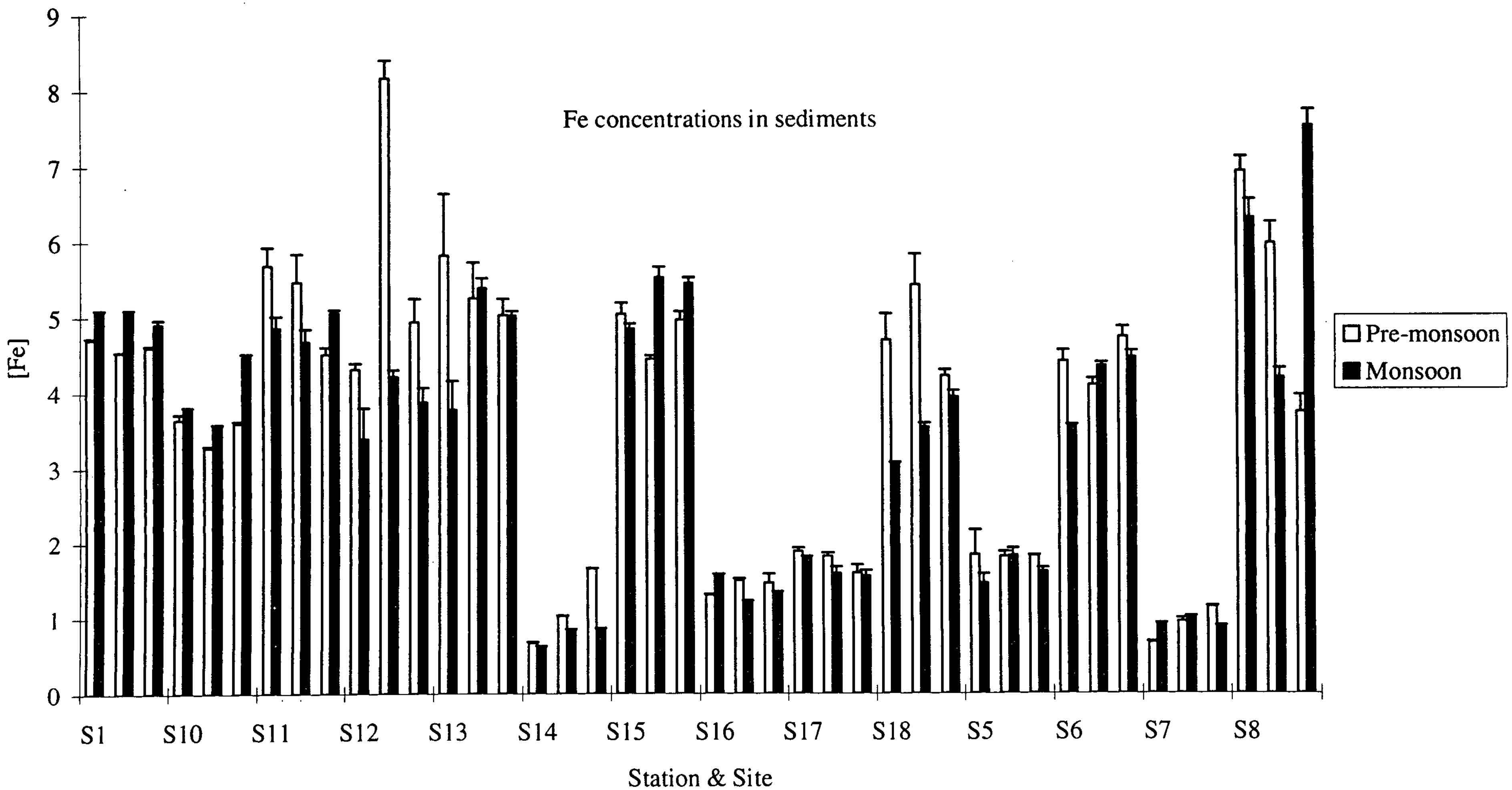


Co concentrations in sediments
[Co]
30
25
20
15
10
5
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site

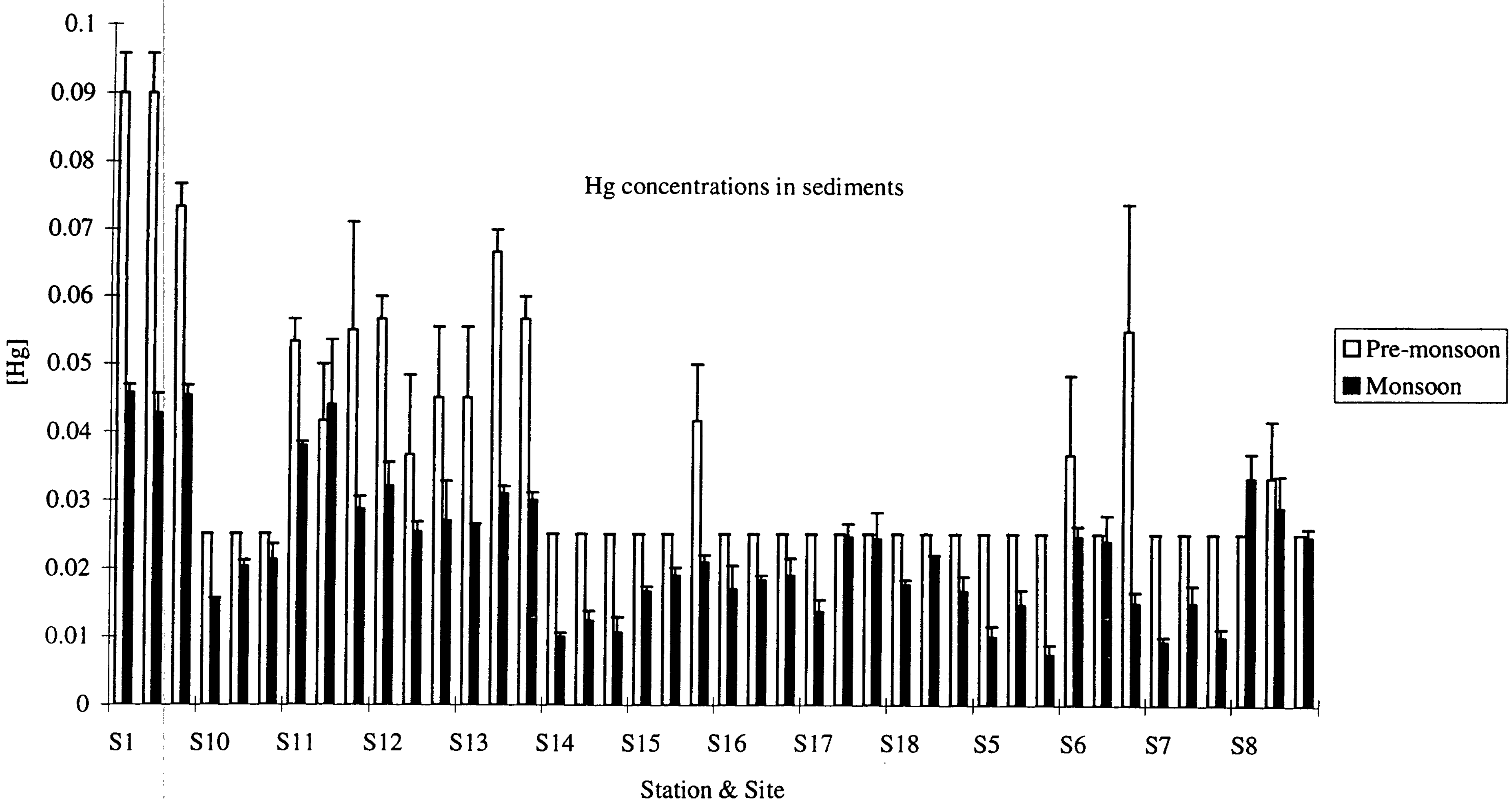


Cr concentrations in sediments
[Cr]
120
100
80
60
40
20
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon

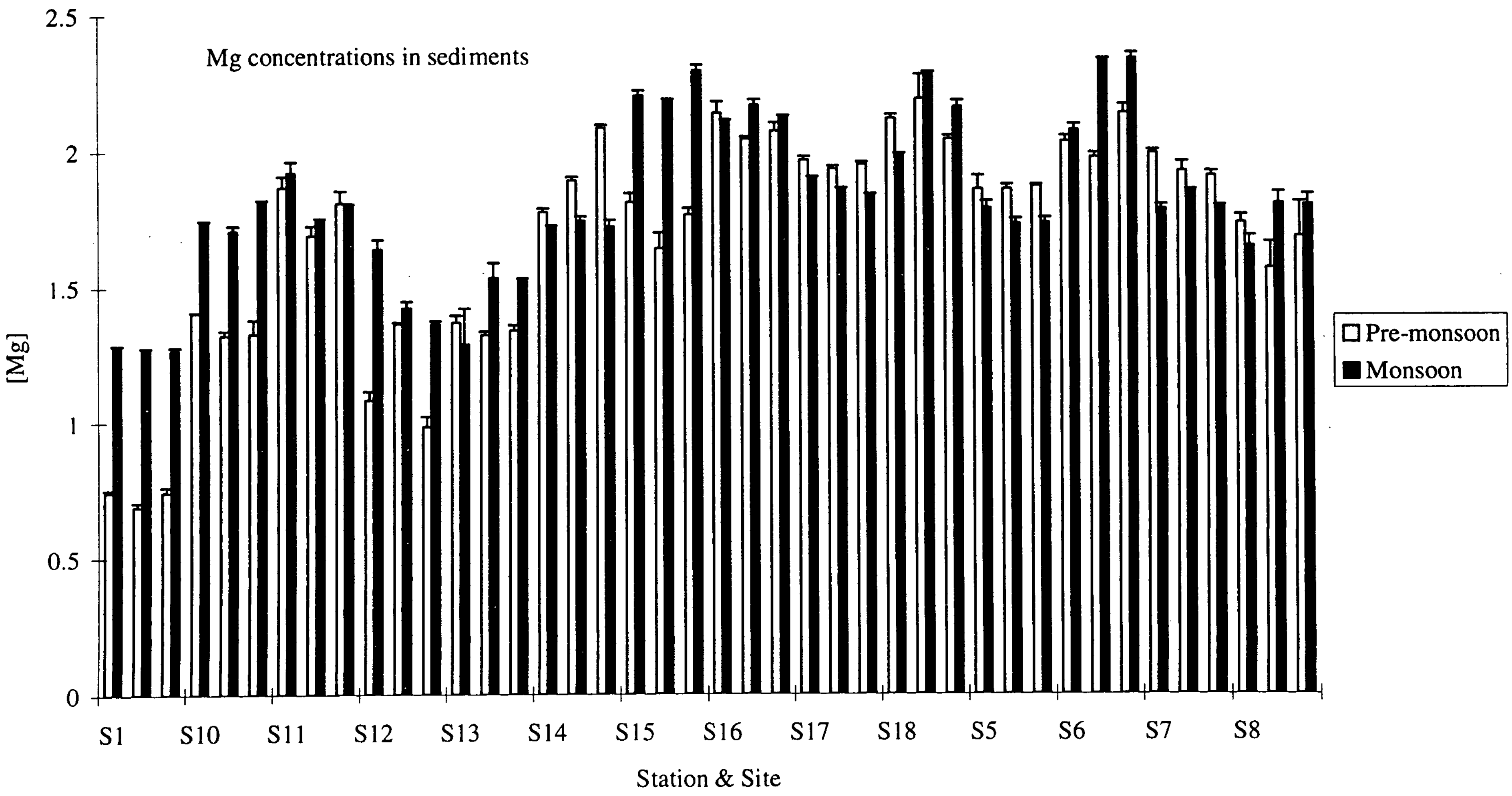

Cu concentrations in sediments
[Cu]
30
25
20
15
10
5
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site

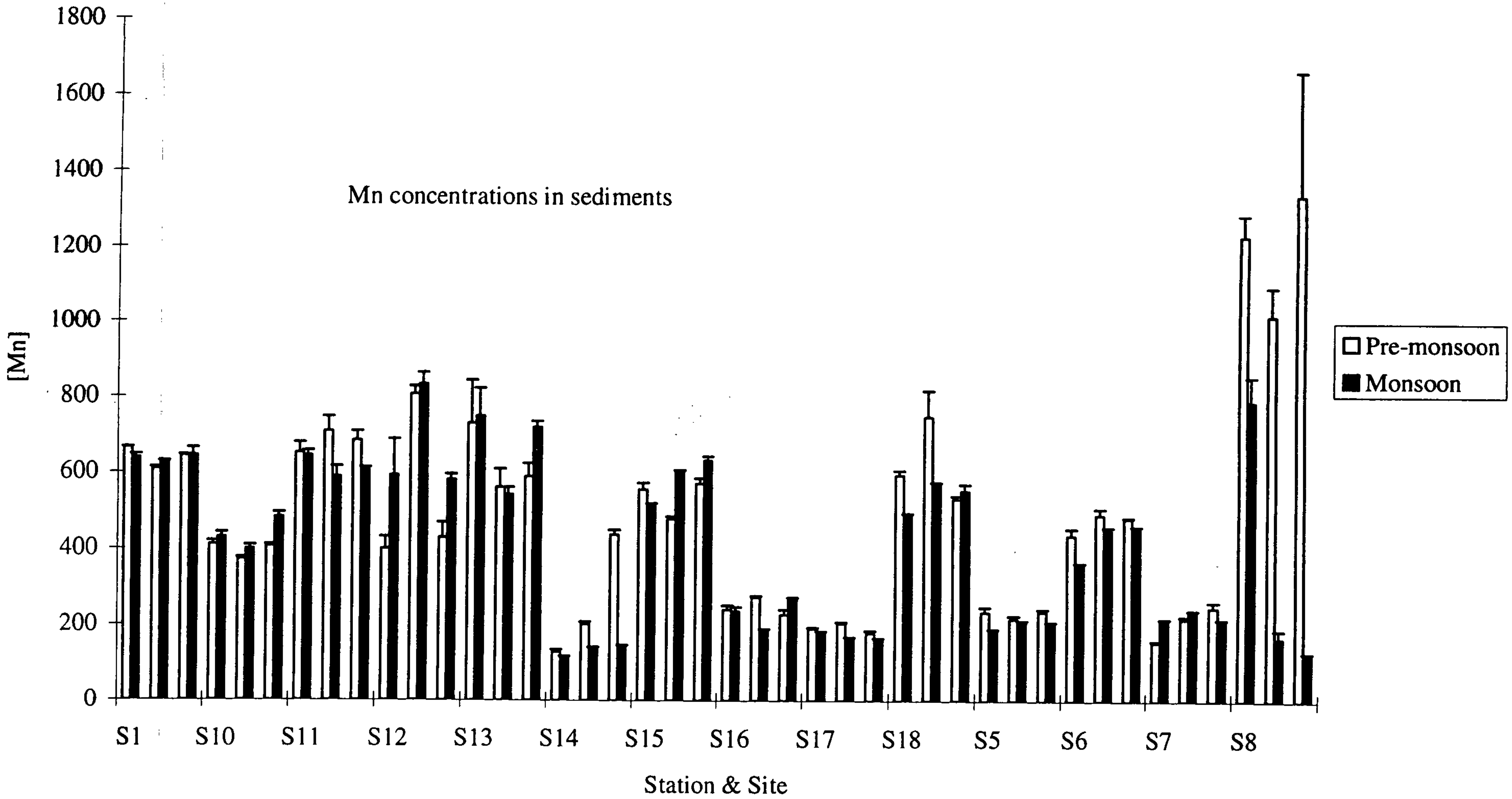


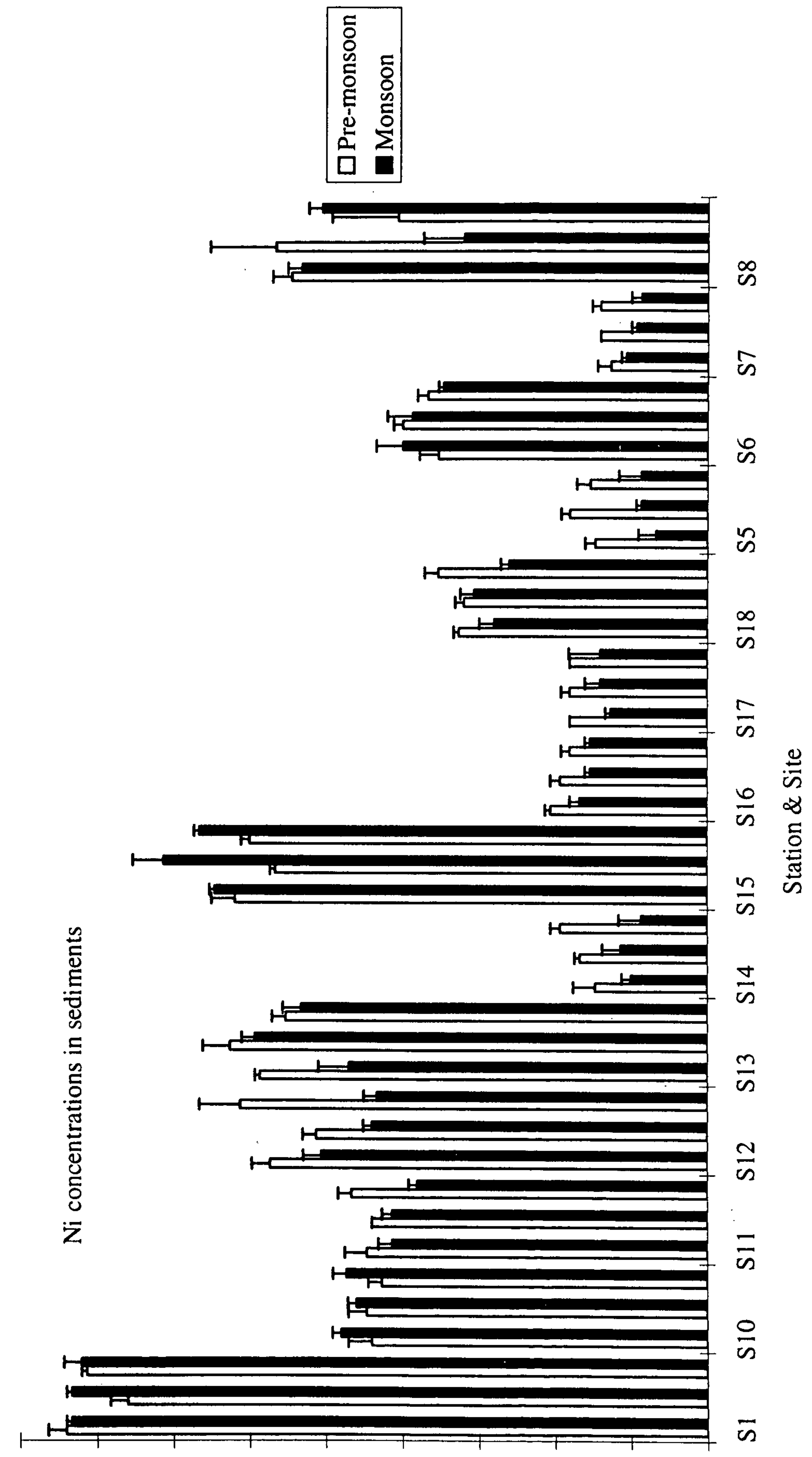
Fe concentrations in sediments
[Fe]
9
8
7
6
5
4
3
2
1
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon



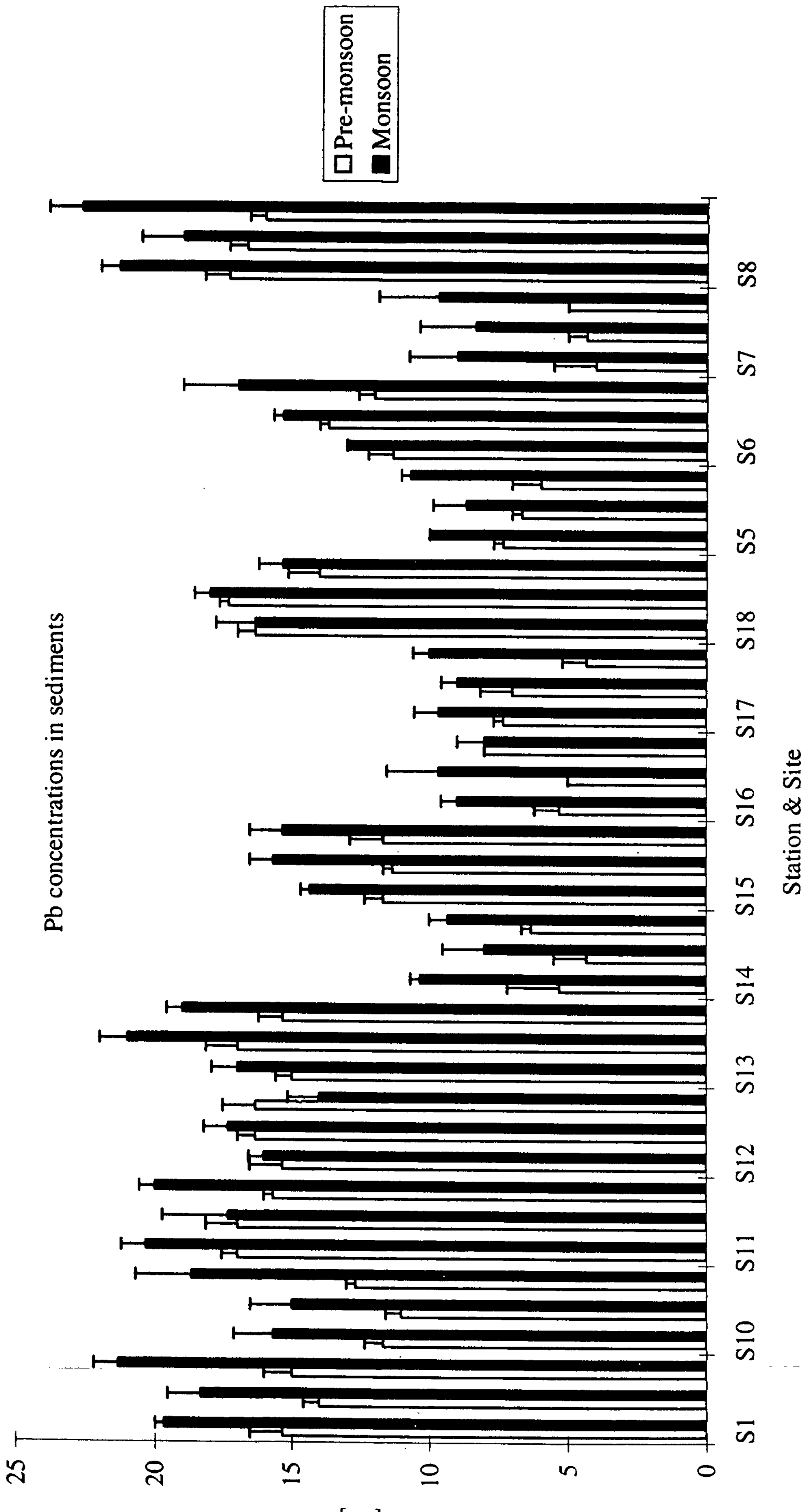
Hg concentrations in sediments
[Hg]
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon

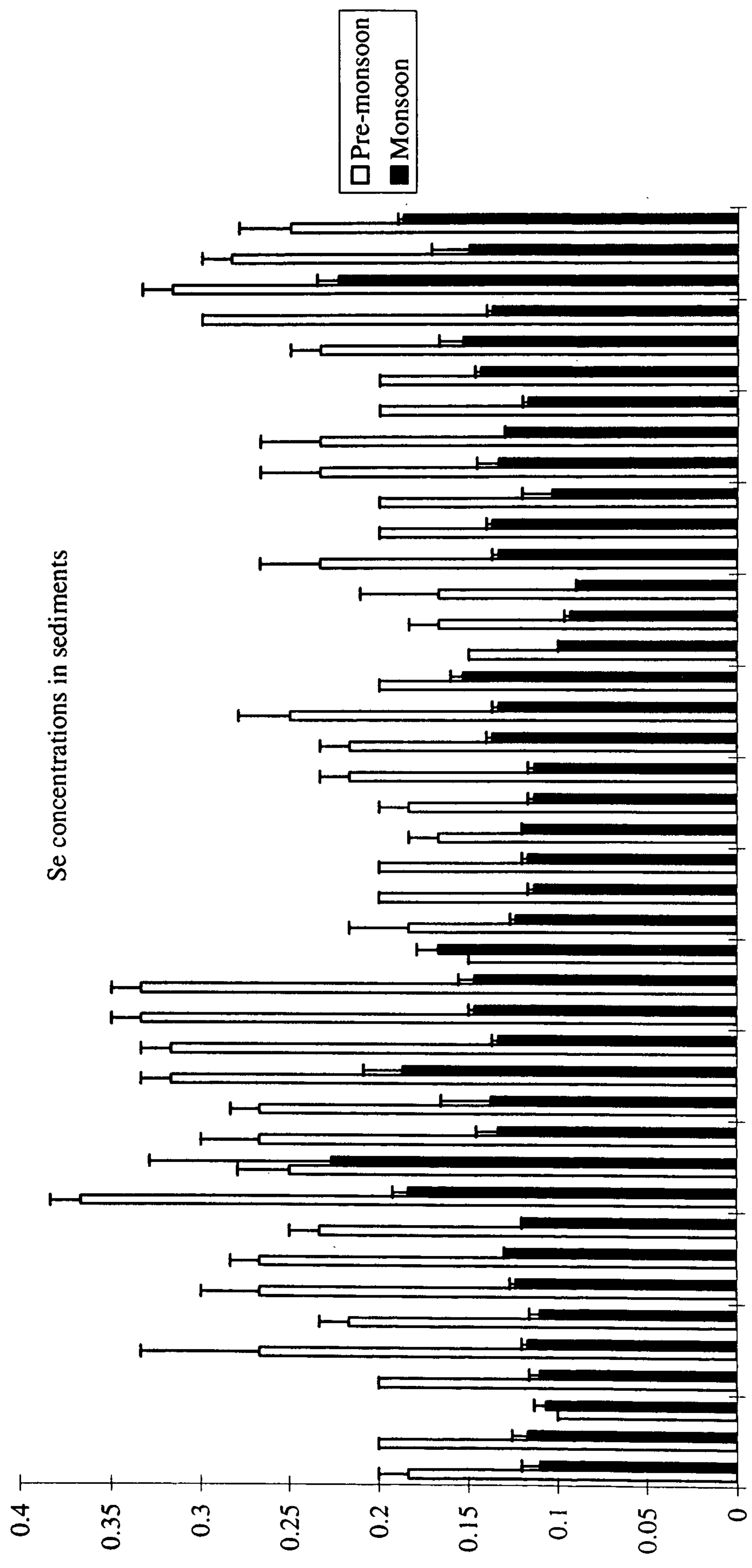

Mg concentrations in sediments
2.5
2
1.5
1
0.5
0
[Mg]
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon

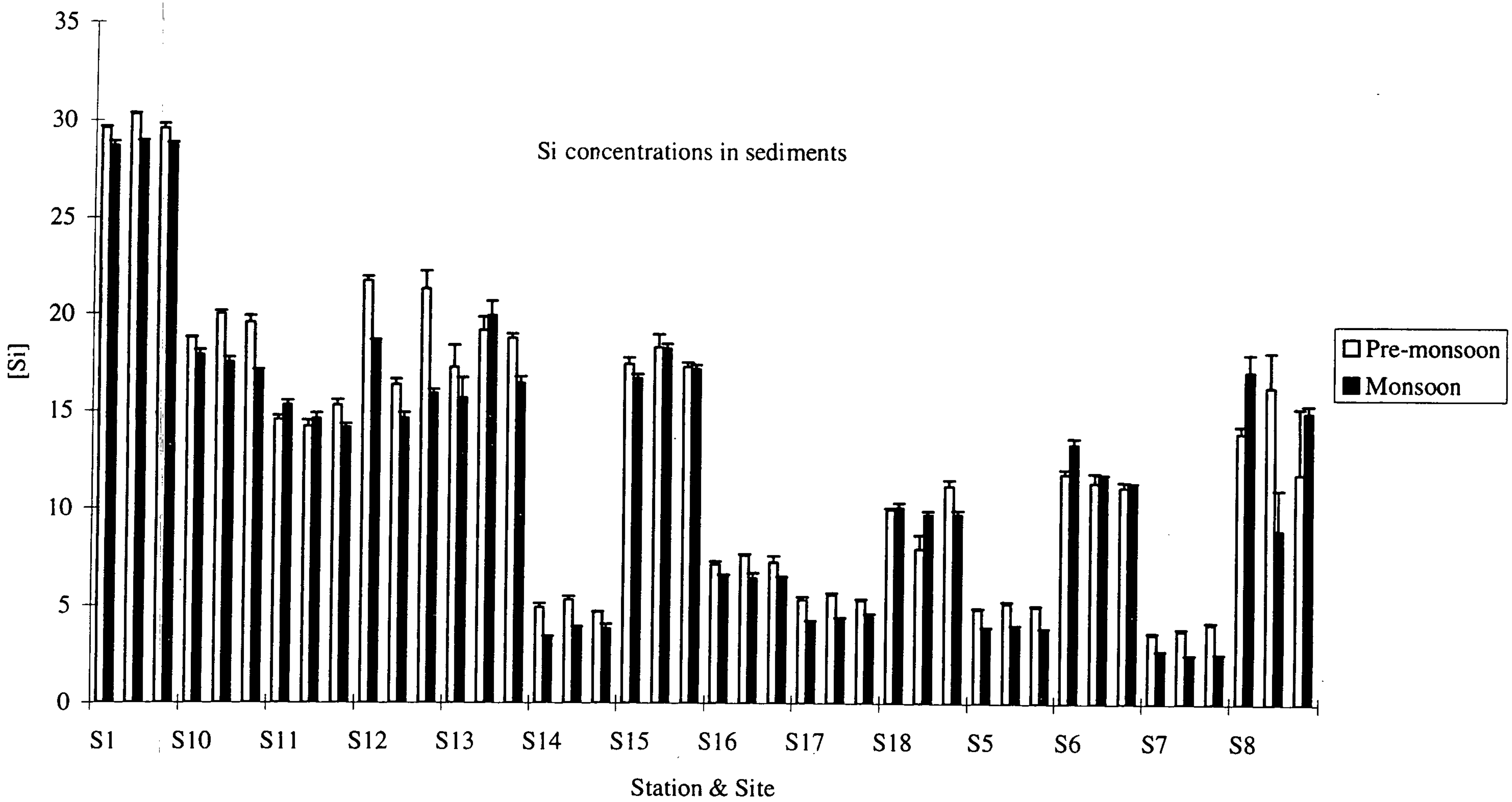

Mn concentrations in sediments
[Mn]
1800
1600
1400
1200
1000
800
600
400
200
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon

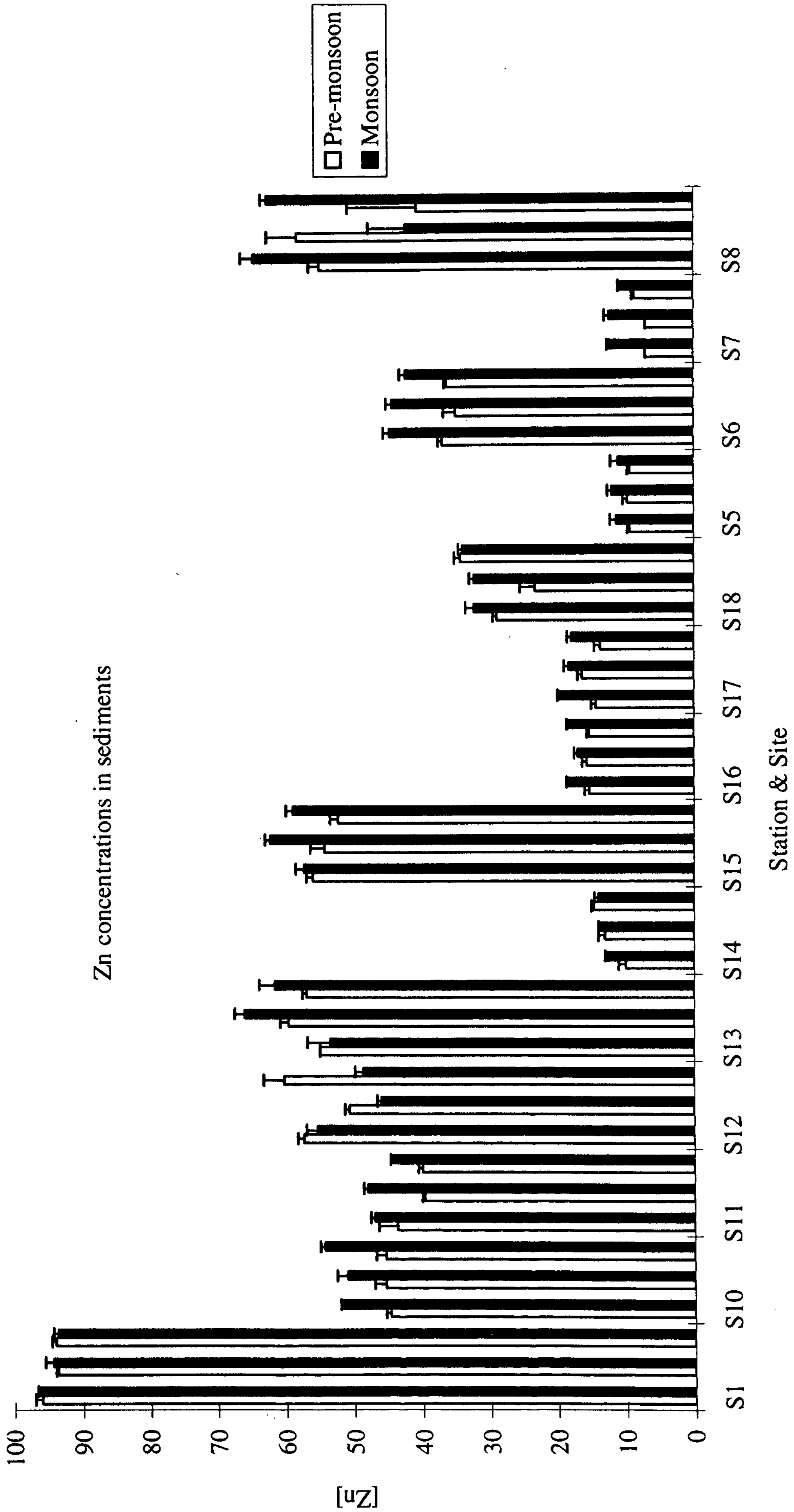


Ni concentrations in sediments
[Ni]
45
40
35
30
25
20
15
10
5
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon


Pb concentrations in sediments
Pre-monsoon
Monsoon
[Pb]
0
5
10
15
20
25
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site


Se concentrations in sediments
Pre-monsoon
Monsoon
[Se]
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site


Si concentrations in sediments
[Si]
35
30
25
20
15
10
5
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site
Pre-monsoon
Monsoon


Zn concentrations in sediments
Pre-monsoon
Monsoon
[Zn]
100
90
80
70
60
50
40
30
20
10
0
S1
S10
S11
S12
S13
S14
S15
S16
S17
S18
S5
S6
S7
S8
Station & Site

APPENDIX 6

Formulae used for the calculation of F ratios and variance components for analysis of variance of sediment trace metal data (on following pages). Homogeneity of variances and normality were checked graphically and both were improved after transformation to natural logs.

F ratios

Factor	F ratio
Season	$F_{season} = MS_{season}/MS_{site}$
Station	$F_{station} = MS_{station}/MS_{site}$
Season X Station	$F_{season\ X\ station} = MS_{season X station}/MS_{site}$
Site(Season X Station)	$F_{site} = MS_{site}/MS_{residual}$

Variance Components

Season = $(MS_{season} - MS_{site})/N$ where N=126 (i.e. 14 stations X 3 sites X 3 replicates)

Station = $(MS_{station} - MS_{site})/N$ where N=18 (i.e. 2 seasons X 3 sites X 3 replicates)

Season X Station = $(MS_{season\ x\ station} - MS_{site})/N$ where N=9 (i.e. 3 sites X 3 replicates)

Site = $(MS_{site} - MS_{residual})/N$ where N=3 (i.e. 3 reps)

Residual = $MS_{residual}$

Analysis of variance (ANOVA) tables comparing the effects of season (pre-monsoon and monsoon), station and site on levels of trace metals and elements in sediments from the Torres Strait. Metal levels were transformed to natural logs prior to analysis. Sampling design is explained in the text. Sources of variation are significant when their p value is less than the adjusted p value of p = 0.003 (see Methods (page 6) for an explanation). Results of Tukey's HSD comparisons of station means for each season are shown below the ANOVA table for each metal; stations are arranged in order of decreasing mean from left to right.

Aluminium

Source of variation	df	SS	MS	% of total variance	F	*p*
Season	1	7.000	7.000	7.03	135.50	< 0.0001
Station	13	162.215	12.478	88.05	241.54	< 0.0001
Season*Station	13	1.755	0.135	1.18	2.61	0.006
Site(Season*Station)	56	2.893	0.052	1.45	2.86	< 0.0001
Residual	169	3.053	0.018	2.30		
Total	252	177.922				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S1>S12=S13=S15=S8=S11=S10=S6>S18>S16>S17=S5=S14>S7
monsoon: S1>S13=S15=S12=S8=S11=S10=S6>S18>S16=S17>S5=S14>S7

Arsenic

Source of variation	df	SS	MS	% of total variance	F	*p*
Season	1	34.560	34.560	27.24	181.91	< 0.0001
Station	13	147.677	11.360	61.97	59.79	< 0.0001
Season*Station	13	5.453	0.419	2.54	2.21	0.02
Site(Season*Station)	56	10.639	0.190	5.36	6.57	< 0.0001
Residual	169	4.888	0.029	2.90		
Total	252	202.816				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S11=S8=S18=S12=S13=S6=S15>S10=S17=S1=S14=S7=S5>S16
monsoon: S8=S11>S15=S18=S12=S6=S13=S10>S1=S17=S7=S5>S14>S16

Calcium

Source of variation	df	SS	MS	% of total variance	F	p
Season	1	0.024	0.024	0.02	0.90	0.35
Station	13	199.880	15.375	95.56	570.89	< 0.0001
Season*Station	13	1.524	0.117	1.40	4.35	< 0.0001
Site(Season*Station)	56	0.108	0.027	0.00	6.71	< 0.0001
Residual	169	0.678	0.004	3.02		
Total	252	208.257				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S7=S14=S17=S5=S16>S6=S18>S11=S8=S15>S10=S13>S12>S1
monsoon: S7=S14=S5=S17=S16>S18>S6>S11=S8=S12=S13=S10=S15>S1

Cadmium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	0.016	0.016	0.00	0.36	0.55
Station	13	28.789	2.215	60.32	49.31	< 0.0001
Season*Station	13	4.381	0.337	17.42	7.50	< 0.0001
Site(Season*Station)	56	2.515	0.045	0.00	2.21	< 0.0001
Residual	169	3.429	0.020	22.26		
Total	252	40.115				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S7>S11=S14=S8=S13=S18=S17=S5=S12>S6=S15=S16=S10>S1
monsoon: S7=S12=S13=S11=S8=S18=S17=S5=S6=S14>S10=S15=S1=S16

Cobalt

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	6.889	6.889	4.49	87.92	< 0.0001
Station	13	197.858	15.220	69.83	194.24	< 0.0001
Season*Station	13	32.613	2.509	22.42	32.02	< 0.0001
Site(Season*Station)	56	4.388	0.078	1.60	3.94	< 0.0001
Residual	169	3.363	0.020	1.66		
Total	252	245.296				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S1=S12=S13=S8=S11=S15=S10=S18=S6>S5=S16=S17=S14=S7
monsoon: S1=S8=S15=S13=S11=S10=S6=S12>S18>S16=S5=S17=S7=S14

Chromium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	4.471	4.471	8.56	90.13	< 0.0001
Station	13	79.219	6.094	81.95	122.85	< 0.0001
Season*Station	13	2.389	0.184	3.63	3.71	0.0003
Site(Season*Station)	56	2.778	0.050	3.17	4.66	< 0.0001
Residual	169	1.797	0.011	2.68		
Total	252	90.559				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S13=S15=S1=S12=S10>S8=S11=S18=S6>S16>S17=S5=S14>S7
monsoon: S15>S10=S1=S13>S8=S12=S11=S18=S6>S16=S5>S17>S14=S7

Copper

Source of variation	df	SS	MS	% of total varition	F	p
Season	1	0.040	0.040	0.00	0.57	0.45
Station	13	73.980	5.691	81.12	80.27	< 0.0001
Season*Station	13	2.760	0.212	4.07	2.99	0.002
Site(Season*Station)	56	3.970	0.071	1.82	1.42	0.05
Residual	169	8.428	0.050	12.99		
Total	252	89.694				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S1>S12=S13=S8=S11=S15=S10=S6=S18>S5=S14=S16=S17=S7
monsoon: S1>S13=S12=S8=S10=S15=S11=S6=S18=S14=S7=S16=S17=S5

Iron

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	0.388	0.388	0.48	4.35	0.04
Station	13	107.502	8.269	92.07	92.75	< 0.0001
Season*Station	13	1.515	0.117	0.63	1.31	0.24
Site(Season*Station)	56	4.993	0.089	5.61	13.90	< 0.0001
Residual	169	1.084	0.006	1.22		
Total	252	115.399				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S12=S8=S13=S11=S15=S18=S1=S6>S10>S5=S17>S16>S14>S7
monsoon: S8=S15=S1=S11=S13=S6=S10=S12=S18>S17=S5>S16>S7>S14

Mercury

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	13.921	13.921	31.95	143.64	< 0.0001
Station	13	34.873	2.683	41.84	27.68	< 0.0001
Season*Station	13	4.265	0.328	7.47	3.39	0.0007
Site(Season*Station)	56	5.427	0.097	4.76	2.02	0.0003
Residual	169	8.119	0.048	13.98		
Total	252	67.775				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S1>S13=S11=S12=S6=S15=S8=S5=S10=S7=S14=S16=S17=S18
monsoon: S1=S11=S13=S8=S12=S6=S17=S15=S10=S18=S16>S7=S14=S5

Magnesium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	0.527	0.527	5.81	47.89	< 0.0001
Station	13	11.235	0.864	67.23	78.49	< 0.0001
Season*Station	13	1.707	0.131	18.92	11.92	< 0.0001
Site(Season*Station)	56	0.617	0.011	3.78	3.70	< 0.0001
Residual	169	0.503	0.003	4.26		
Total	252	15.267				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S18=S16=S6=S17=S7=S14=S5=S11=S15=S8>S10=S13>S12>S1
monsoon: S6=S15=S18=S16>S17=S11=S7=S5=S10=S8=S14>S12=S13>S1

Manganese

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	1.560	1.560	2.56	7.82	0.007
Station	13	64.771	4.982	63.09	24.98	< 0.0001
Season*Station	13	11.059	0.851	17.17	4.26	< 0.0001
Site(Season*Station)	56	11.170	0.199	15.04	22.43	< 0.0001
Residual	169	1.503	0.009	2.14		
Total	252	90.503				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S8>S11=S1=S18=S13=S15=S12=S6=S10>S16=S5=S14=S7=S17
monsoon: S13=S12=S1=S11=S15=S18>S10=S6>S8=S16=S7=S5>S17>S14

Nickel

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	2.373	2.373	3.28	63.66	< 0.0001
Station	13	113.287	8.714	85.23	233.74	< 0.0001
Season*Station	13	3.758	0.289	4.95	7.75	< 0.0001
Site(Season*Station)	56	2.088	0.037	0.00	1.00	0.49
Residual	169	6.330	0.037	6.54		
Total	252	128.446				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S1>S15=S13=S12=S8=S11=S10=S6=S18>S16=S17=S14=S5=S7
monsoon: S1=S15=S13=S10=S12=S8=S11=S6=S18>S16=S17=S7=S14=S5

Lead

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	5.713	5.713	16.36	118.42	< 0.0001
Station	13	41.317	3.178	63.29	65.88	< 0.0001
Season*Station	13	2.406	0.185	5.54	3.84	0.0002
Site(Season*Station)	56	2.701	0.048	1.33	1.31	0.10
Residual	169	6.229	0.037	13.47		
Total	252	58.288				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S8=S11=S12=S18=S13=S1=S6=S10=S15>S5=S16=S17=S14=S7
monsoon: S8=S1=S11=S13=S18=S10=S12=S15=S6>S5=S17=S14=S16=S7

Selenium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	17.500	17.500	75.11	234.74	< 0.0001
Station	13	8.281	0.637	18.82	8.54	< 0.0001
Season*Station	13	0.797	0.061	3.01	0.82	0.64
Site(Season*Station)	56	4.175	0.075	1.44	2.62	< 0.0001
Residual	169	4.800	0.028	1.62		
Total	252	35.483				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S13=S12=S8=S14=S11=S7=S10=S6=S17=S5=S15=S16=S18=S1
monsoon: S8=S12=S14=S13=S7=S17=S6=S11=S5=S15=S16=S10=S1=S18

Silicon

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	0.897	0.879	1.34	26.52	< 0.0001
Station	13	110.782	8.522	94.16	257.04	< 0.0001
Season*Station	13	1.080	0.083	1.11	2.51	0.009
Site(Season*Station)	56	1.857	0.033	1.60	3.80	< 0.0001
Residual	169	1.473	0.009	1.80		
Total	252	116.828				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S1>S12=S10=S13=S15>S11=S8=S6=S18>S16>S17=S5=S14>S7
monsoon: S1>S10=S15=S13=S12=S11>S8=S6>S18>S16>S17>S5=S14>S7

Zinc

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	1.124	1.124	1.52	37.32	< 0.0001
Station	13	127.759	9.828	95.01	326.26	< 0.0001
Season*Station	13	0.927	0.070	0.80	2.37	0.01
Site(Season*Station)	56	1.687	0.030	1.28	3.88	< 0.0001
Residual	169	1.310	0.008	1.40		
Total	252	133.656				

Comparison of station means (by Tukey's HSD test):

pre-monsoon: S1>S13=S12=S15=S8=S10=S11=S6>S18>S16=S17>S14>S5>S7
monsoon: S1>S15=S13=S8=S10=S12=S11=S6>S18>S17=S16>S14>S7=S5

Procedures used by Queensland Department of Primary Industry (Animal Research Institute) for Trace Metal Analysis of Biological Samples

Prepared by H Mawhinney and E McElroy

Apparatus

All analyses were carried out on a standard Perkin-Elmer Sciex ELAN™ 5000 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS).

Materials and Methods

All plastic-ware used for the preparation of standard solutions and for dilution and storage of sample digests was soaked in nitric acid (10%) for a minimum of 48 hours. All items were then rinsed three times using reverse osmosis (RO) prepared water followed by three further rinsings with polished reverse osmosis (ROP) prepared water (18M Ω).

All borosilicate glass volumetric flasks were fitted with PTFE stoppers. These flasks and the PTFE beakers were refluxed with HNO_3 (conc.) for eight hours, allowed to cool, rinsed three times with RO water and then soaked and cleaned as per plastic-ware.

Mixed multi-elemental standard solutions were prepared from 1000 ng/L stock solutions. Aluminium standards were prepared separately in TPX (polymethylpentane) volumetric flasks. The adsorption/release equilibriums of glass with aluminium in solution make low level determinations of this element in glass highly inaccurate. Tin standards were also prepared separately in glass, daily from concentrate.

HNO_3

Nitric acid was purified by sub-boiling double distillation of reagent grade feedstocks in quartz stills.

Sample Preparation

Sample dissolution was achieved using a HNO_3 microwave assisted digestion. The system used a was a Microwave Laboratory Systems MLS 1200 manufactured by MILESTONE, Italy.

Nitric acid was specially prepared by double distillation of AR grade acid in sub-boiling point quartz stills.

All samples were freeze-dried and ground to a fine powder to achieve an homogeneous final product. 100-200 mg of this material was accurately weighed into a TFM insert of the microwave digestion system. HNO_3 (4 ml) was added and the vessels sealed and placed in the microwave oven. The oven program used was:-

Step (1)250 watts for eight minutes
Step (2)400 watts for four minutes
Step (3)250 watts for four minutes

It should be noted that 250 watts power with this system is a continuous energy output which results in more even and controlled heating producing a gradual pressure increase to a maximum of 30 bar.

The vessels were then removed from the oven and cooled in an ice-bath for a minimum of one hour. This step is necessary to avoid losses of sample as an aerosol upon opening of the vessels. The sample solution is then transferred to a PTFE beaker and made up to 10.0 g with ROP water. 3.0 g of this solution is transferred to a polypropylene tube. This tube is set aside for mercury and tin determinations.

The remaining 7.0 g of sample solution in the beaker is taken to near dryness on a ceramic hotplate at 90^{0}C. A further 2 ml of HNO_3 and 2 ml of H_2O_2 is added dropwise and again taken to near dryness. This step is included to ensure complete digestion and to remove volatile interfering matrix components. The digestion solution is washed into a 50 ml polypropylene tube using 1% HNO_3 and accurately made up to 20.0 g. This tube is used for solution nebulization ICP-MS.

Running Procedures

Each set of digestions contain eight samples, a standard reference material (SRM) and either a blank or a duplicate sample. This is maintained for all samples that are digested using the above procedure.

The samples are run on the ICP-MS using solution nebulization. A set of calibration standards are run and then the digest solutions including SRM's, blanks and duplicate samples. For the purposes of the method all readings must lie between the lowest and highest standard concentration on the calibration curve. If readings are below the reading of the lowest standard concentration then a more concentrated solution must be run and if the readings are above the highest concentration a dilution of the sample must be run.

All standard concentrations must be within the linear dynamic range on the calibration curve. Calibration check solutions and blanks are also analysed in the run sequence and the instrument is recalibrated by reanalysing all standard solutions every three hours.

This method of analysis exceeds the guidelines set out in our quality control manual accredited by the National Association of Testing Authorities, Australia (NATA).

APPENDIX 8

Summary of trace metal levels (in mg/kg dry weight) in burrowing clams in both seasons, throughout the Torres Strait. Symbols in the table have the following meanings: PM = pre-monsoon; M = monsoon; SD = standard deviation; bdl = below detection limits. N = 40 for each station in both seasons with the following exceptions: Warrior Reef pre-monsoon (N = 33) and monsoon (N = 25); Bramble Reef pre-monsoon (N = 36); Campbell Reef monsoon (N = 39).

STATION	TIME	Value	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sr	U	Zn
Dungeness Rf	PM	Mean	0.53	27.11	584.75	100.17	163.25	5.24	2.81	1583.25	0.50	11272.50	1175.50	19.18	47.35	754.75	4.30	18.42
		SD	0.803	34.180	160.464	47.180	42.389	1.665	1.429	427.073	0.283	2811.514	375.383	6.660	8.472	209.700	1.888	19.527
		Max	3.10	190.00	950.00	190.00	280.00	9.00	9.10	3000.00	1.60	18000.00	2100.00	388.00	65.00	1300.00	9.10	86.00
		Min	0.03	3.50	300.00	3.90	100.00	2.90	1.10	700.00	bdl	6200.00	600.00	9.10	31.00	360.00	1.90	3.10
	M	Mean	0.46	5.35	547.44	120.41	143.67	3.95	1.94	1272.05	0.76	15287.18	1009.74	20.43	34.48	599.49	2.51	49.49
		SD	0.747	2.770	161.925	56.170	49.424	1.527	0.785	717.808	0.232	9158.062	467.341	7.581	18.014	205.439	1.451	52.999
		Max	3.60	14.00	890.00	240.00	340.00	7.00	5.10	4400.00	1.30	53500.00	3200.00	46.00	83.00	980.00	5.90	210.00
		Min	bdl	2.10	300.00	28.00	62.00	1.60	0.91	280.00	0.40	5900.00	360.00	8.80	9.60	290.00	0.49	3.60
Poll Is	PM	Mean	0.32	51.09	494.50	70.63	137.88	4.64	1.96	1347.50	0.79	13427.50	1892.75	23.60	54.28	848.00	3.48	4.84
		SD	0.501	79.559	193.801	28.315	40.916	1.808	0.658	480.821	0.481	3984.842	556.039	8.915	11.152	225.175	1.863	3.239
		Max	1.20	300.00	930.00	130.00	230.00	11.00	3.60	2400.00	2.30	23000.00	3100.00	44.00	83.00	1300.00	10.00	19.00
		Min	bdl	2.50	170.00	10.00	26.00	2.00	0.61	430.00	0.10	3000.00	410.00	4.90	35.00	100.00	0.79	1.20
	M	Mean	0.38	4.23	523.03	59.15	106.18	3.99	2.07	947.88	0.84	10818.18	1785.15	20.30	25.33	762.73	2.57	6.57
		SD	0.664	1.106	215.051	15.881	27.648	1.832	0.872	264.407	0.217	3014.595	542.587	10.521	7.100	182.453	1.464	5.488
		Max	3.10	26.00	1100.00	140.00	210.00	10.00	6.30	2500.00	1.40	22200.00	4100.00	41.00	95.00	1700.00	4.90	39.00
		Min	bdl	0.83	230.00	18.00	86.00	1.00	0.89	250.00	0.38	3600.00	1100.00	14.00	22.00	390.00	0.77	2.50

STATION	TIME	Value	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sr	U	Zn
Warrior Rf	PM	Mean	1.53	15.30	565.26	179.66	145.76	3.93	3.43	1468.42	0.65	16700.00	957.63	28.41	53.61	996.05	2.59	139.51
		SD	2.172	23.426	213.424	68.999	41.396	1.635	6.125	555.695	0.171	3870.331	601.010	9.670	9.336	225.898	1.617	84.960
		Max	11.00	100.00	1000.00	330.00	250.00	7.60	40.00	3500.00	1.00	26000.00	1200.00	58.00	78.00	1600.00	5.20	320.00
		Min	0.08	1.50	180.00	100.00	69.00	1.20	1.30	660.00	0.34	8500.00	380.00	9.60	37.00	620.00	0.54	5.10
	M	Mean	3.24	5.73	604.57	192.31	115.51	3.56	3.03	1092.29	0.80	15406.00	744.86	23.39	24.40	936.86	1.69	263.86
		SD	4.725	3.509	201.645	57.755	35.273	1.597	4.781	490.516	0.333	6594.893	262.369	12.857	7.720	202.030	0.891	184.975
		Max	6.20	7.90	920.00	330.00	220.00	9.60	30.00	2300.00	1.30	25900.00	1300.00	52.00	40.00	1200.00	4.20	380.00
		Min	0.11	3.90	290.00	66.00	69.00	2.10	1.00	480.00	0.38	910.00	430.00	5.80	11.00	680.00	0.47	2.10
Rennel Rf	PM	Mean	0.53	27.54	494.25	130.53	152.78	3.84	2.86	1284.75	0.84	17597.50	1140.75	27.80	58.15	891.00	3.20	162.30
		SD	1.426	41.772	126.529	47.579	40.678	1.253	0.975	373.184	0.308	3697.295	374.490	7.707	12.211	178.553	1.086	115.416
		Max	9.00	190.00	770.00	200.00	240.00	7.00	7.50	2200.00	2.00	26000.00	2500.00	45.00	82.00	1200.00	6.60	510.00
		Min	0.04	4.40	100.00	29.00	96.00	1.50	1.50	100.00	0.43	9900.00	690.00	15.00	32.00	520.00	1.80	3.00
	M	Mean	0.53	5.47	515.25	146.4	120.63	3.48	2.51	1163.5	1.18	16565	1080.25	23.66	40.33	704.25	2.8	182.6
		SD	0.725	2.652	147.021	45.269	34.683	1.113	1.048	459.155	0.329	4800.617	353.934	6.048	14.373	194.434	1.504	96.856
		Max	3.60	16.00	900.00	270.00	210.00	6.50	6.20	2600.00	2.10	31200.00	2100.00	39.00	65.00	1100.00	6.30	400.00
		Min	0.01	2.20	280.00	60.00	63.00	1.50	0.51	300.00	0.57	5900.00	490.00	7.50	10.00	290.00	0.43	4.10
Kokope Rf	PM	Mean	4.16	37.56	576.25	255.00	150.05	3.46	3.29	1564.75	0.87	25100.00	684.50	39.53	55.00	899.25	3.30	440.25
		SD	3.082	54.636	185.827	85.515	58.428	1.161	0.931	468.013	0.359	5158.016	269.814	9.738	14.299	253.381	1.102	159.623
		Max	12.00	220.00	900.00	530.00	400.00	6.60	6.70	3200.00	2.10	40000.00	1800.00	63.00	94.00	1300.00	5.60	1000.00
		Min	0.66	3.20	210.00	110.00	67.00	1.50	1.80	990.00	0.43	15000.00	330.00	24.00	31.00	450.00	1.70	240.00
	M	Mean	5.05	6.57	552.5	220.58	117.53	2.26	2.76	945.25	1.04	19692.5	628.5	29.28	24.16	791.5	1.96	435.7
		SD	4.185	3.545	167.543	59.725	27.074	0.937	0.958	518.81	0.336	6357.728	151.701	8.227	8.547	244.431	1.013	166.219
		Max	19.00	24.00	980.00	330.00	210.00	4.60	5.60	1900.00	2.00	31200.00	1000.00	50.00	38.00	1700.00	4.10	880.00
		Min	0.27	1.80	280.00	68.00	65.00	0.74	1.50	250.00	0.51	3800.00	300.00	14.00	7.30	390.00	0.29	98.00

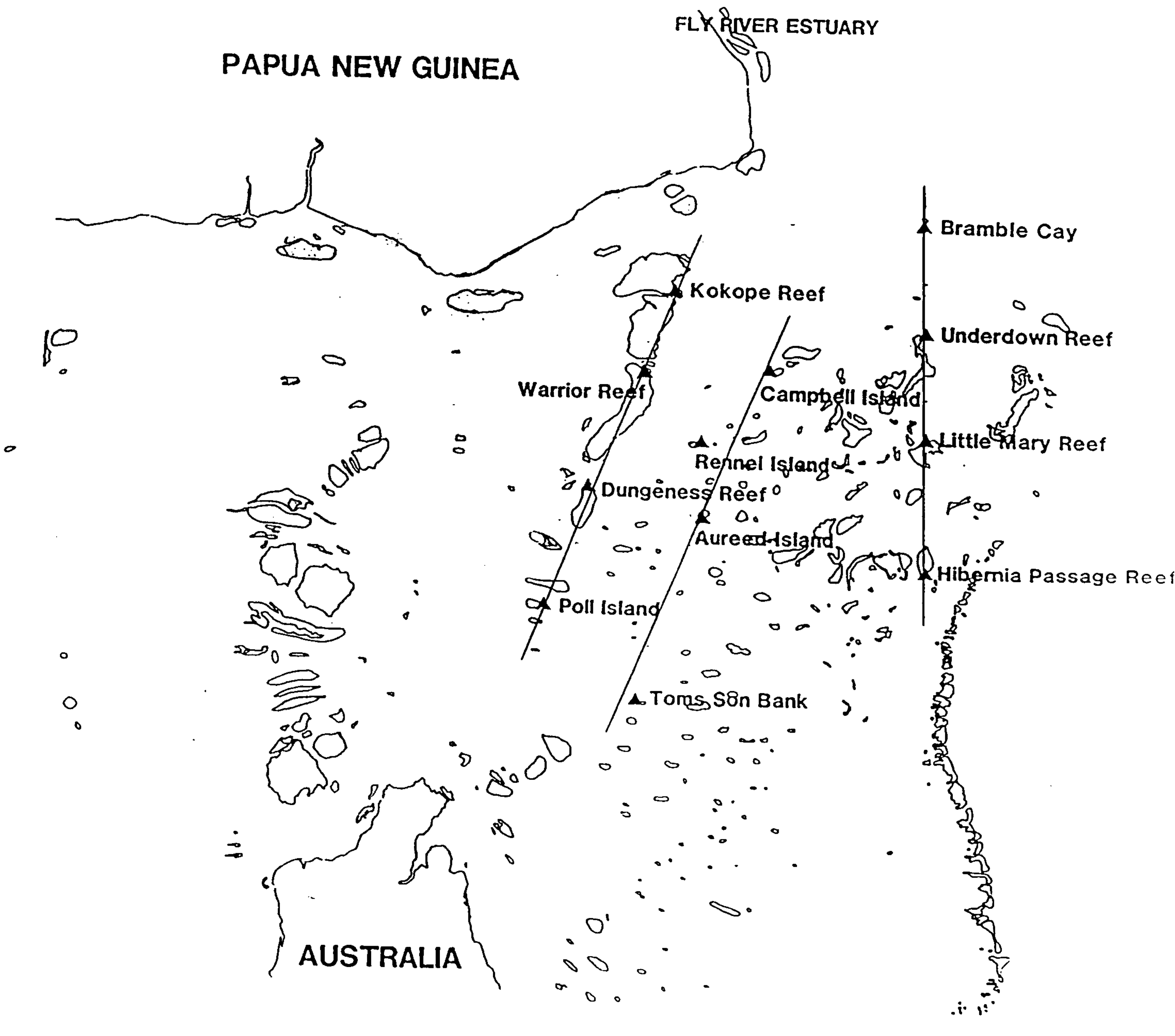
STATION	TIME	Value	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sr	U	Zn
Bramble Rf	PM	Mean	1.22	22.58	449.47	157.47	159.63	3.03	4.24	1250.79	1.07	16576.32	918.16	38.37	50.97	988.42	3.63	782.89
		SD	1.661	28.973	142.145	64.349	70.979	0.917	2.000	450.953	0.314	6301.884	392.689	11.746	13.639	270.580	2.232	283.843
		Max	6.00	110.00	840.00	300.00	400.00	4.80	11.00	2300.00	1.70	28000.00	2600.00	54.00	79.00	1600.00	14.00	1500.00
		Min	0.05	2.30	240.00	32.00	87.00	1.30	2.10	660.00	0.61	7700.00	440.00	15.00	27.00	100.00	1.10	420.00
	M	Mean	0.4	22	470	114.35	108.2	9.33	3.41	985.25	1.35	14245	672.75	33.13	23.03	759.5	2.22	887.75
		SD	0.525	12.347	124.982	46.395	36.574	14.608	1.424	347.245	0.391	4083.673	223.48	9.861	7.619	146.829	0.823	246.758
		Max	3.20	80.00	930.00	210.00	230.00	81.00	8.90	1600.00	2.20	27400.00	1200.00	71.00	42.00	1200.00	4.20	1500.00
		Min	0.03	2.00	270.00	25.00	51.00	1.80	1.70	170.00	0.62	3700.00	320.00	16.00	6.80	490.00	0.80	410.00
Underdown Rf	PM	Mean	0.24	20.54	381.00	69.61	117.45	4.00	3.01	940.25	0.83	10950.00	1189.75	21.08	55.95	929.50	2.99	38.75
		SD	0.297	33.677	148.303	39.229	36.470	1.250	1.011	245.331	0.310	2847.851	429.069	7.257	16.072	261.602	1.209	34.693
		Max	1.70	200.00	880.00	170.00	200.00	8.10	5.30	1600.00	1.70	18000.00	2500.00	41.00	96.00	1700.00	5.90	170.00
		Min	0.04	1.60	130.00	1.20	10.00	2.20	1.40	460.00	0.36	5600.00	490.00	8.20	27.00	450.00	1.00	1.30
	M	Mean	0.57	7.89	396.5	61.78	111.38	10.13	2.23	823.5	0.6	10890	1161.5	20.2	24.43	802.5	2.11	87.88
		SD	0.719	4.817	107.716	36.631	30.622	7.817	0.976	218.603	0.167	2741.776	477.69	5.436	7.779	172.519	1.239	114.34
		Max	3.10	23.00	640.00	140.00	220.00	36.00	5.40	1400.00	1.00	19100.00	2600.00	37.00	43.00	1300.00	5.90	510.00
		Min	0.02	3.00	200.00	1.10	68.00	3.30	1.20	360.00	0.33	6000.00	550.00	11.00	13.00	470.00	0.85	1.60
Campbell Rf	PM	Mean	0.23	11.87	524.25	95.93	143.00	3.27	2.82	1150.75	1.09	18950.00	1067.75	25.85	60.83	992.50	2.66	128.40
		SD	0.351	24.719	152.431	49.041	32.957	1.008	0.924	390.873	0.751	4955.960	393.137	6.290	10.884	199.933	0.969	78.993
		Max	1.90	120.00	800.00	240.00	220.00	5.60	7.50	2300.00	3.30	30000.00	1800.00	43.00	94.00	1400.00	5.20	370.00
		Min	0.02	2.10	250.00	3.60	84.00	1.20	1.60	630.00	0.25	11000.00	620.00	16.00	41.00	660.00	1.10	5.30
	M	Mean	0.41	6	509.23	104.79	137.31	4.89	2.56	951.03	1.14	15310.26	1070.51	20.39	24.74	751.79	2.46	235.49
		SD	1.203	2.817	149.55	42.733	37.723	3.562	0.879	448.159	0.374	5262.419	325.77	8.482	9.372	163.56	1.362	123.514
		Max	7.50	17.00	930.00	180.00	230.00	20.00	6.30	1800.00	2.10	27200.00	1800.00	48.00	49.00	1100.00	6.80	540.00
		Min	0.03	2.40	210.00	16.00	78.00	1.10	1.50	260.00	0.51	5800.00	530.00	7.70	13.00	400.00	0.47	10.00

STATION	SEASON	Value	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sr	U	Zn
Aureed Rf	PM	Mean	0.35	10.54	496.50	88.12	139.93	5.03	2.75	1214.75	1.23	15750.00	1244.00	26.33	66.78	944.50	3.39	65.56
		SD	0.727	13.181	184.774	42.254	45.232	1.421	0.514	507.695	0.792	3119.418	449.882	6.666	12.067	197.484	1.200	46.129
		Max	4.50	64.00	810.00	190.00	240.00	7.70	3.60	2400.00	3.40	25000.00	2500.00	46.00	90.00	1500.00	6.40	170.00
		Min	0.02	1.90	220.00	7.60	55.00	3.00	1.60	330.00	0.29	10000.00	500.00	15.00	40.00	670.00	1.80	3.50
	M	Mean	0.31	4.66	497.5	80.8	114.13	4.16	2.18	1026.5	1.07	15687.5	1230	23.93	53.75	782.75	3.26	76.07
		SD	0.482	2.335	167.236	39.216	29.475	1.758	1.161	578.546	0.265	4256.59	307.496	6.677	14.237	166.317	1.704	61.531
		Max	2.90	14.00	900.00	200.00	220.00	11.00	8.60	3500.00	1.80	28800.00	2300.00	47.00	91.00	1200.00	8.90	310.00
		Min	0.01	1.60	280.00	5.90	68.00	1.40	0.86	230.00	0.62	7800.00	760.00	12.00	26.00	430.00	0.85	4.40
Little Mary Rf	PM	Mean	0.38	10.61	372.75	55.81	110.73	5.01	2.35	916.25	0.86	13400.00	1569.75	20.80	69.00	950.50	5.47	10.33
		SD	0.552	17.172	120.128	30.486	23.982	2.023	0.685	333.072	0.572	3746.588	503.330	6.056	11.620	214.033	2.544	9.108
		Max	2.30	51.00	670.00	120.00	180.00	11.00	4.60	2700.00	2.20	24000.00	3200.00	33.00	92.00	1400.00	10.00	42.00
		Min	0.02	2.30	180.00	2.60	57.00	1.90	1.20	570.00	bdl	4700.00	780.00	12.00	48.00	540.00	1.80	2.70
	M	Mean	0.32	14.21	390.75	45.59	91.63	7.05	2.14	797.25	0.72	10652.5	1399	17.29	25.28	725.25	2.94	15.37
		SD	0.422	6.569	159.846	20.319	19.029	9.578	1.432	161.086	0.237	2817.981	341	5.2	7.425	159.019	1.399	17.431
		Max	1.80	36.00	730.00	92.00	150.00	65.00	10.00	1300.00	1.40	19200.00	2300.00	31.00	52.00	970.00	7.90	71.00
		Min	0.01	2.60	140.00	1.10	60.00	2.20	1.30	330.00	0.40	4600.00	810.00	8.80	14.00	360.00	1.30	3.80
Hibernia Pass	PM	Mean	0.93	4.86	458.75	36.69	109.68	5.88	2.21	890.75	0.59	7940.00	1992.50	19.20	68.05	994.25	3.72	4.37
		SD	0.944	6.263	148.465	21.903	26.805	2.531	0.722	220.051	0.376	1981.168	639.867	4.664	13.747	233.248	2.080	3.915
		Max	3.70	19.00	760.00	91.00	160.00	12.00	5.80	1500.00	1.90	12000.00	3600.00	28.00	91.00	1400.00	12.00	22.00
		Min	0.04	0.66	170.00	1.50	71.00	3.40	1.20	660.00	0.17	4800.00	1100.00	12.00	43.00	100.00	1.00	1.20
	M	Mean	0.38	3.66	365	31.23	79.1	5.58	1.56	712.75	0.74	6827.5	1725	13.11	22.75	767.25	2.45	4.62
		SD	0.546	2.123	119.293	19.722	20.875	3.22	0.4	173.16	0.186	2037.468	537.563	3.542	4.803	140.985	1.056	2.095
		Max	2.40	9.10	660.00	68.00	130.00	18.00	2.50	1200.00	1.20	12500.00	3100.00	22.00	34.00	1100.00	5.60	14.00
		Min	bdl	1.20	160.00	0.86	32.00	1.80	0.78	280.00	0.38	3400.00	550.00	4.70	12.00	470.00	0.62	1.20

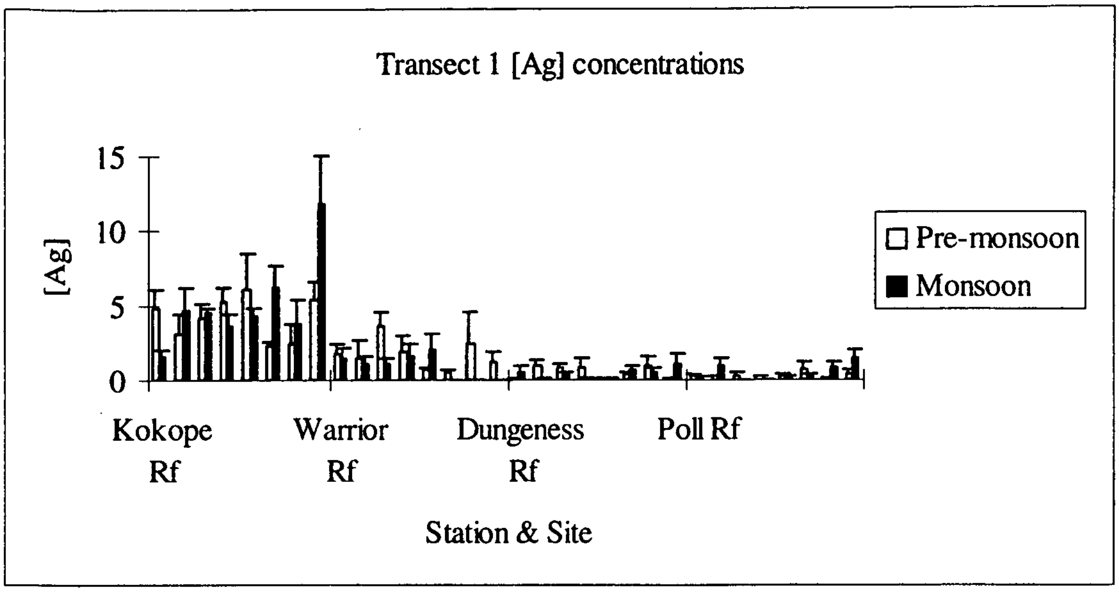
STATION	SEASON	Value	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sr	U	Zn
Tom Son's Bk	PM	Mean	0.40	12.27	531.00	42.31	137.25	4.85	3.41	1189.50	0.51	10515.00	2153.50	25.10	64.25	919.75	3.21	6.93
		SD	0.657	21.943	128.179	26.701	41.181	1.980	5.094	352.573	0.332	3079.173	688.386	8.044	12.424	191.760	1.671	10.360
		Max	3.20	120.00	1000.00	110.00	210.00	10.00	26.00	2400.00	1.50	18000.00	3900.00	52.00	96.00	1500.00	7.60	54.00
		Min	0.02	1.60	270.00	3.70	10.00	2.30	1.30	770.00	0.09	4900.00	940.00	10.00	38.00	510.00	1.10	0.40
	M	Mean	0.53	4.27	510.75	57.18	102.45	3.88	2.25	943.5	0.82	10405	1711.5	20.1	24.2	749.5	2.51	6.26
		SD	0.955	1.111	207.505	15.464	26.814	1.833	1.177	275.9	0.221	2988.778	532.948	9.603	7.14	185.858	1.372	5.08
		Max	4.10	7.80	990.00	100.00	180.00	10.00	6.60	1600.00	1.30	22400.00	3200.00	56.00	42.00	1200.00	7.40	34.00
		Min	bdl	2.40	190.00	35.00	58.00	1.50	1.00	470.00	0.38	5500.00	550.00	7.80	13.00	360.00	0.96	2.40

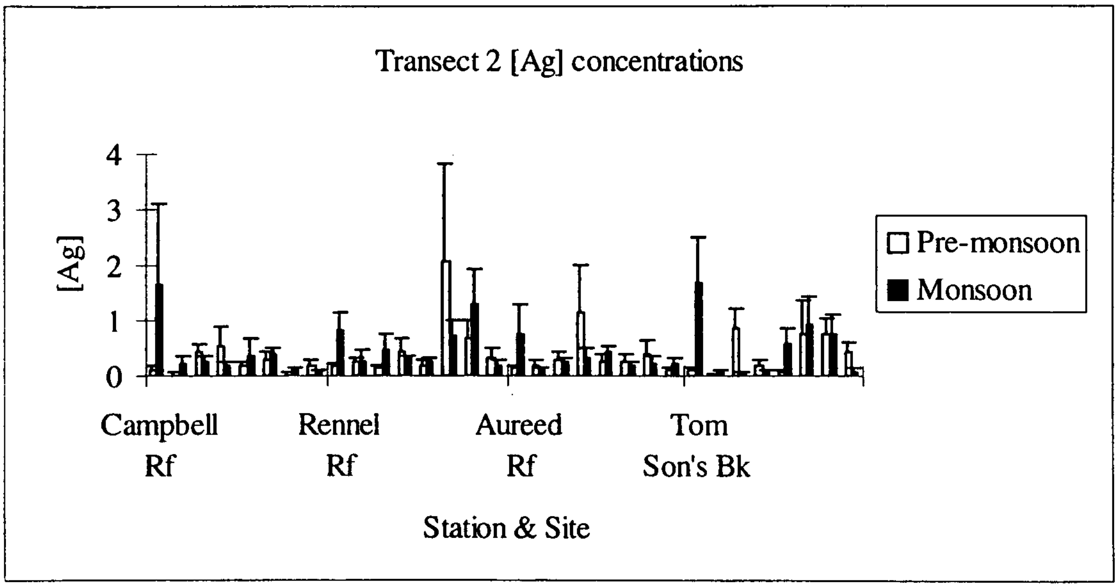
APPENDIX 9 (on following pages)

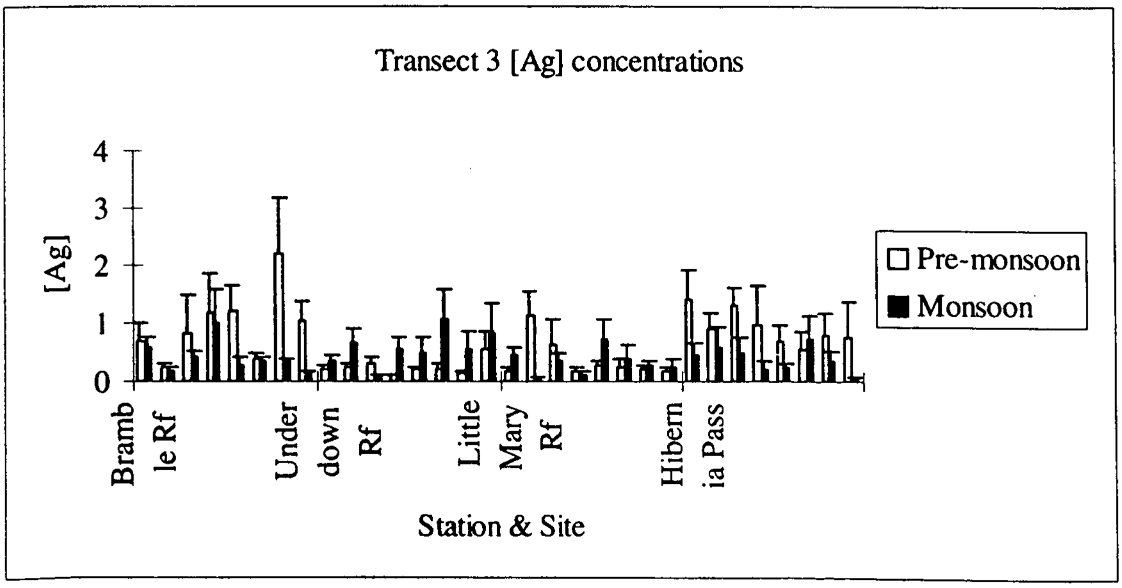
Trace metal concentrations (in mg/kg dry weight) in kidneys of the burrowing clam (*T. crocea*) in pre-monsoon and monsoon seasons in the Torres Strait. Stations are viewed in three north-south transects, as recommended in the Pilot Study, and shown on the map on the following page. Data shown are means and standard errors for each of eight sites in each station; N=5 replicates per site (i.e. a total of 40 clams per station) with the following exceptions: Warrior Reef pre-monsoon (N=33 from eight sites) and monsoon (N=25 from five sites); Bramble Reef pre-monsoon (N=36 from eight sites); Campbell Reef monsoon (N=39 from eight sites).

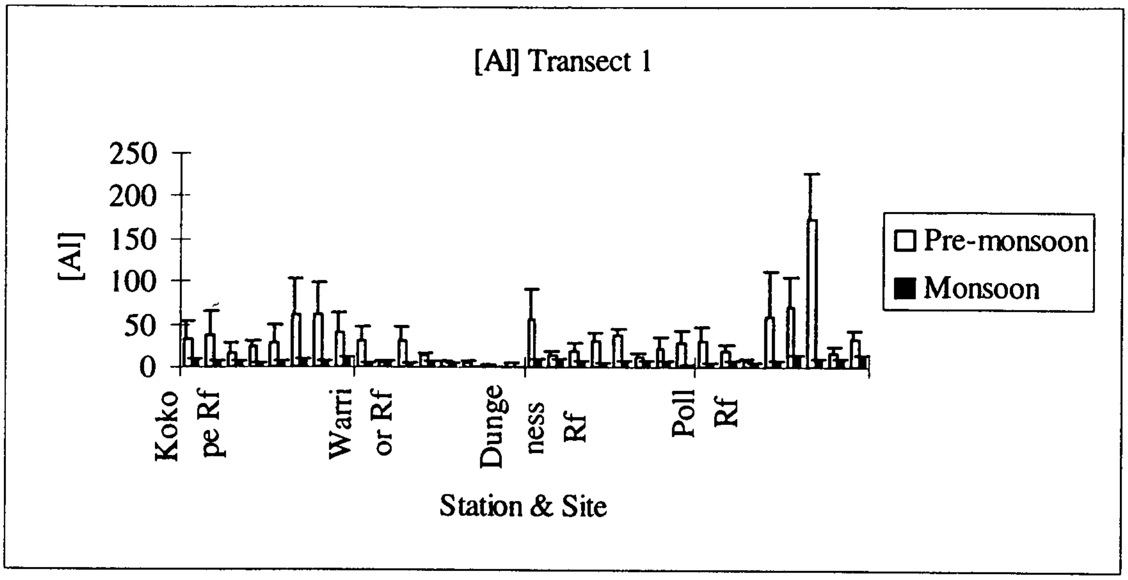


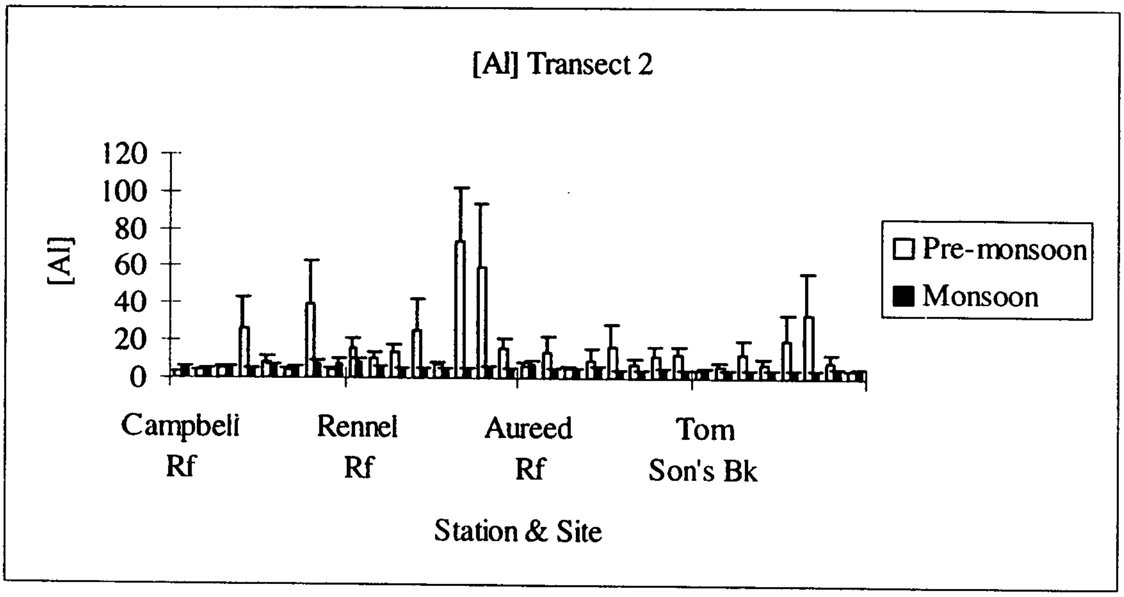
Locations of the three transects are compared on the following pages.


Transect 1 [Ag] concentrations
15
10
5
0
[Ag]
Pre-monsoon
Monsoon
Kokope Rf
Warrior Rf
Dungeness Rf
Poll Rf
Station & Site


Transect 2 [Ag] concentrations
4
3
2
1
0
[Ag]
Pre-monsoon
Monsoon
Campbell Rf
Rennel Rf
Aureed Rf
Tom Son's Bk
Station & Site


Transect 3 [Ag] concentrations
4
3
2
1
0
[Ag]
Pre-monsoon
Monsoon
Bramb le Rf
Under down Rf
Little Mary Rf
Hibern ia Pass
Station & Site


[Al] Transect 1
250
200
150
100
50
0
[Al]
Koko pe Rf
Warri or Rf
Dunge ness Rf
Poll Rf
Station & Site
Pre-monsoon
Monsoon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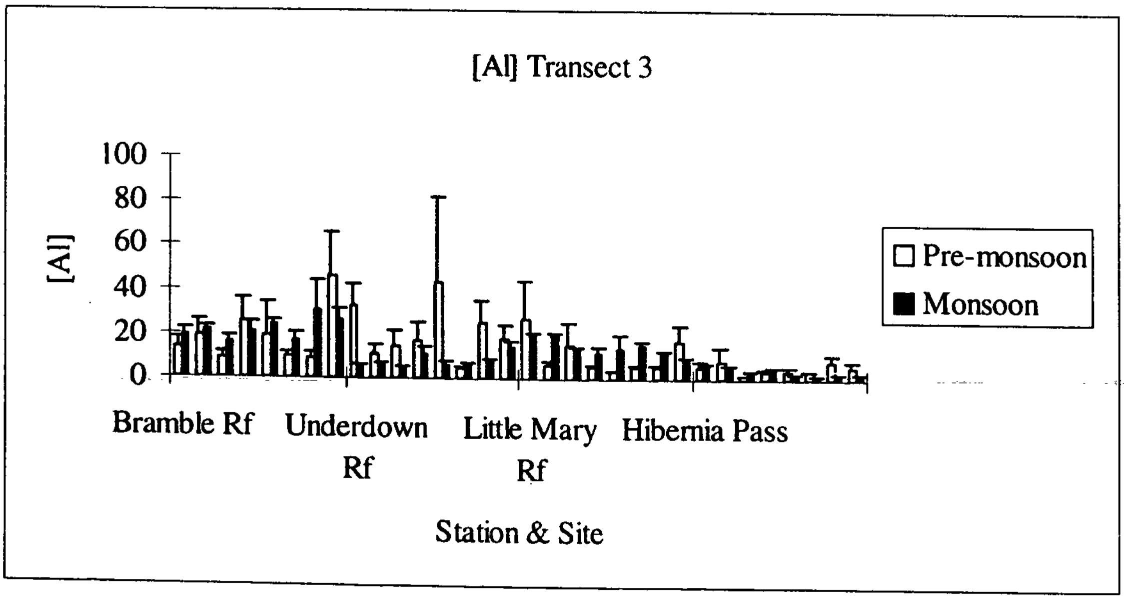
80
60
40
20
0
[Al]
Campbell Rf
Rennel Rf
Aureed Rf
Tom Son's Bk
Station & Site
Pre-monsoon
Monsoon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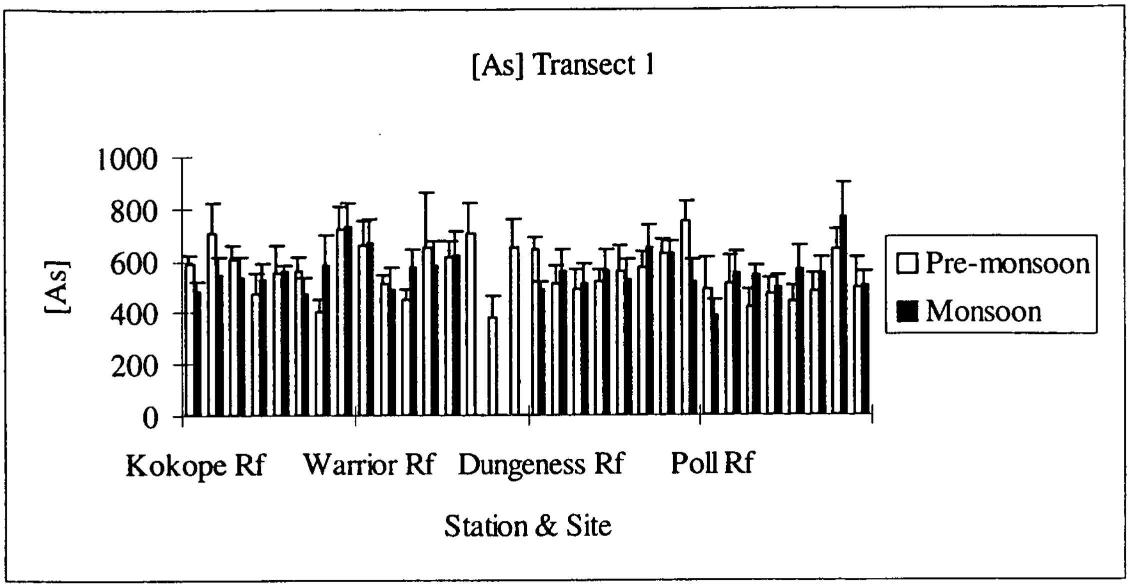
80
60
40
20
0
[Al]
Bramble Rf
Underdown Rf
Little Mary Rf
Hibernia Pass
Station & Site
Pre-monsoon
Monsoon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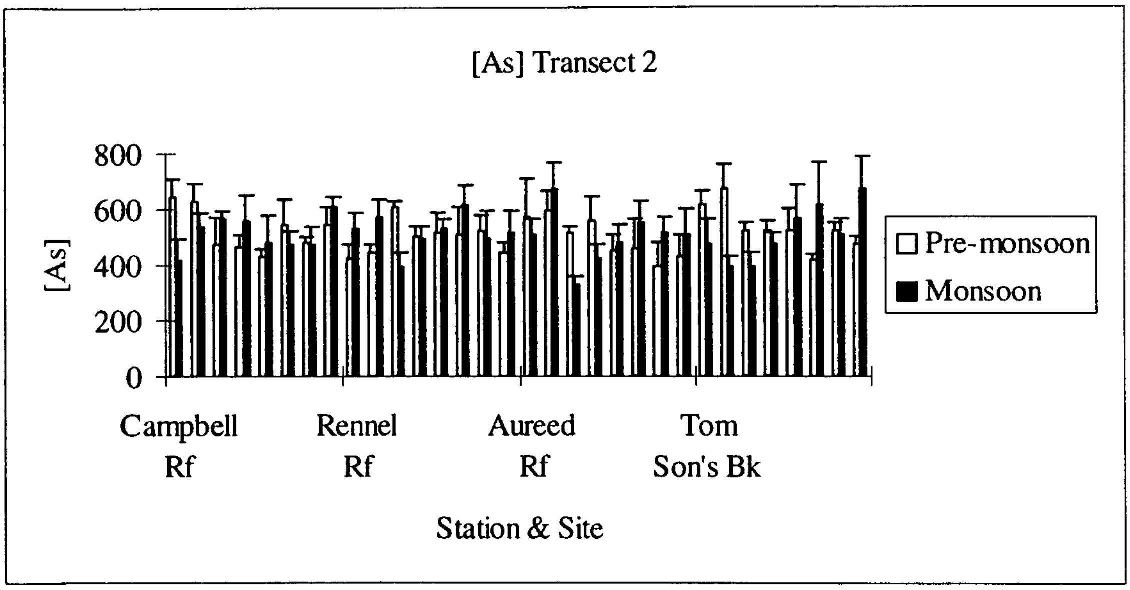
1000
800
600
400
200
0
[As]
Pre-monsoon
Monsoon
Kokope Rf
Warrior Rf
Dungeness Rf
Poll Rf
Station & Site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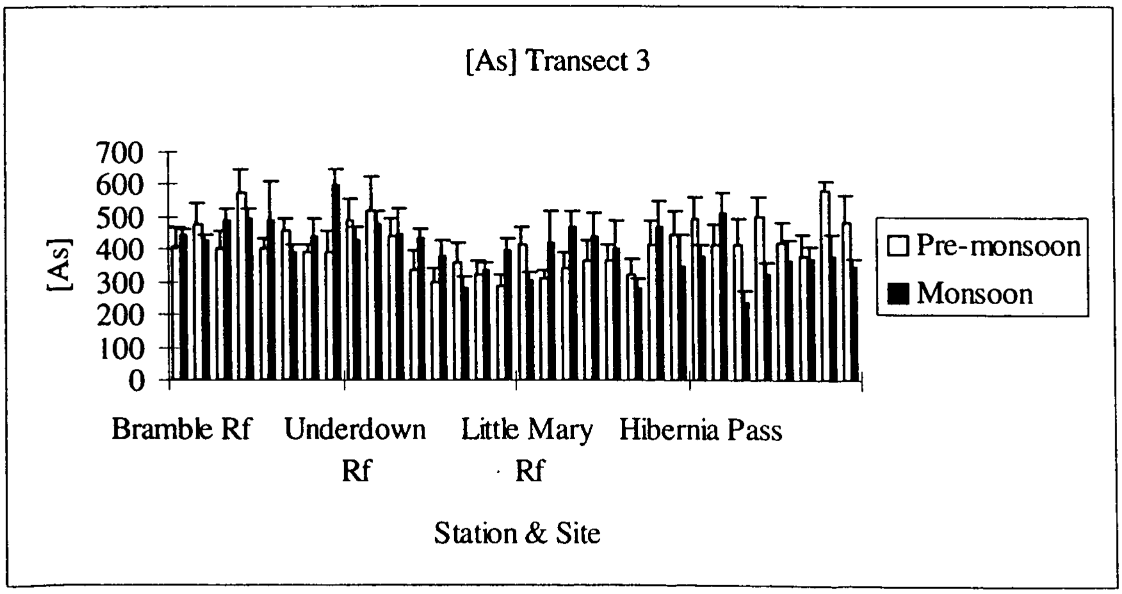
Station & Site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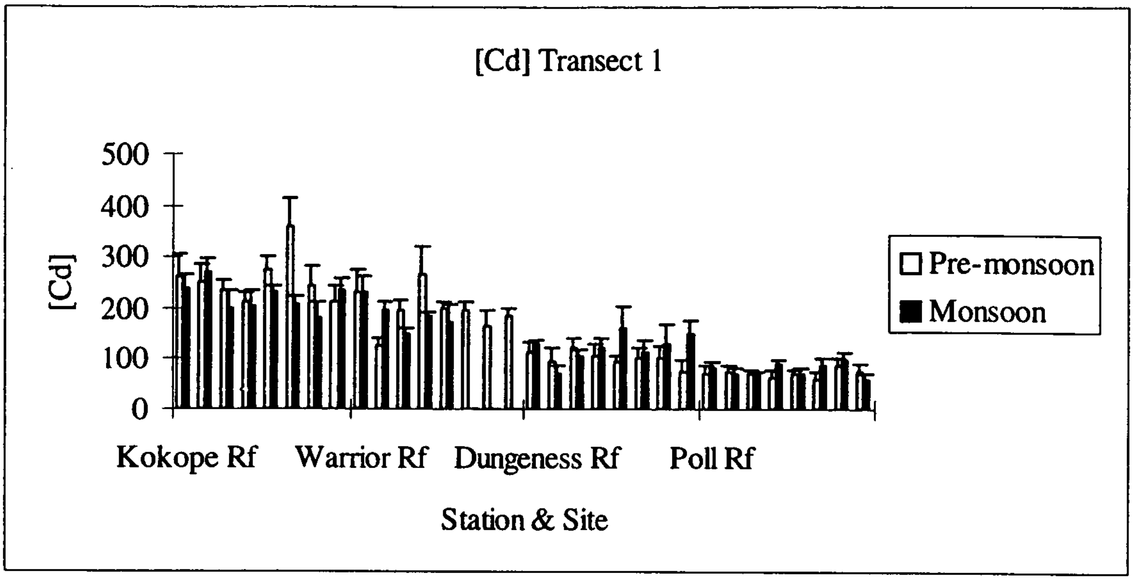
Station & Site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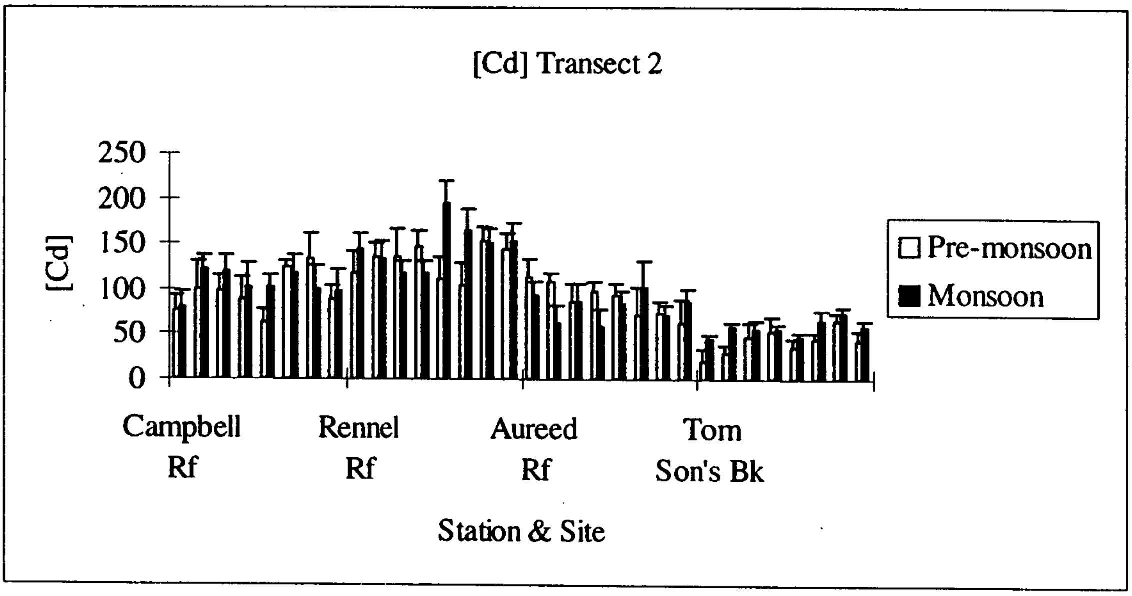
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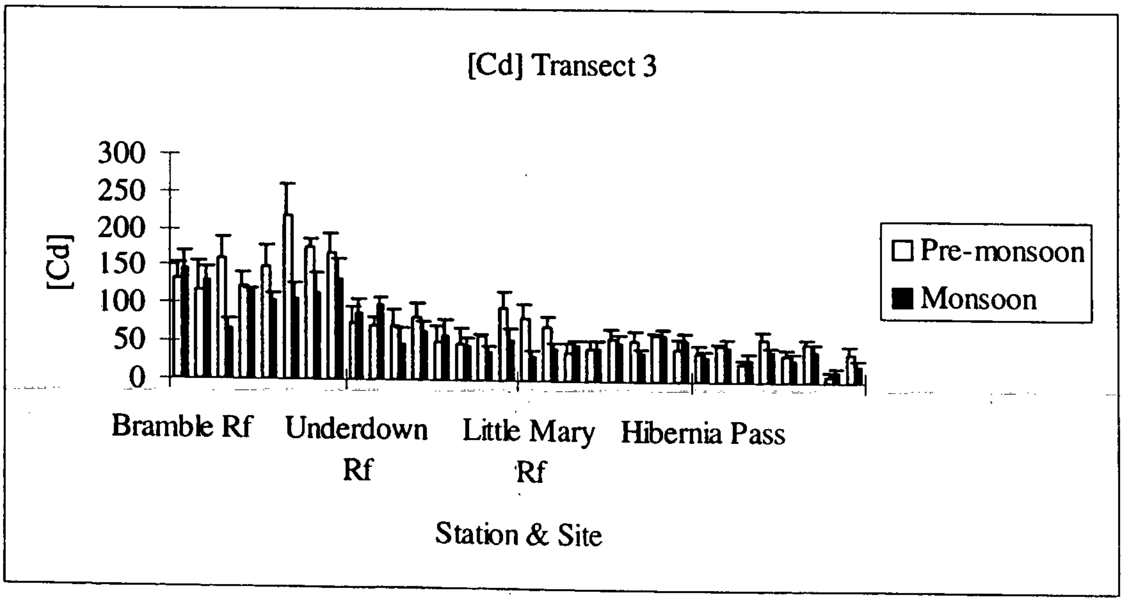
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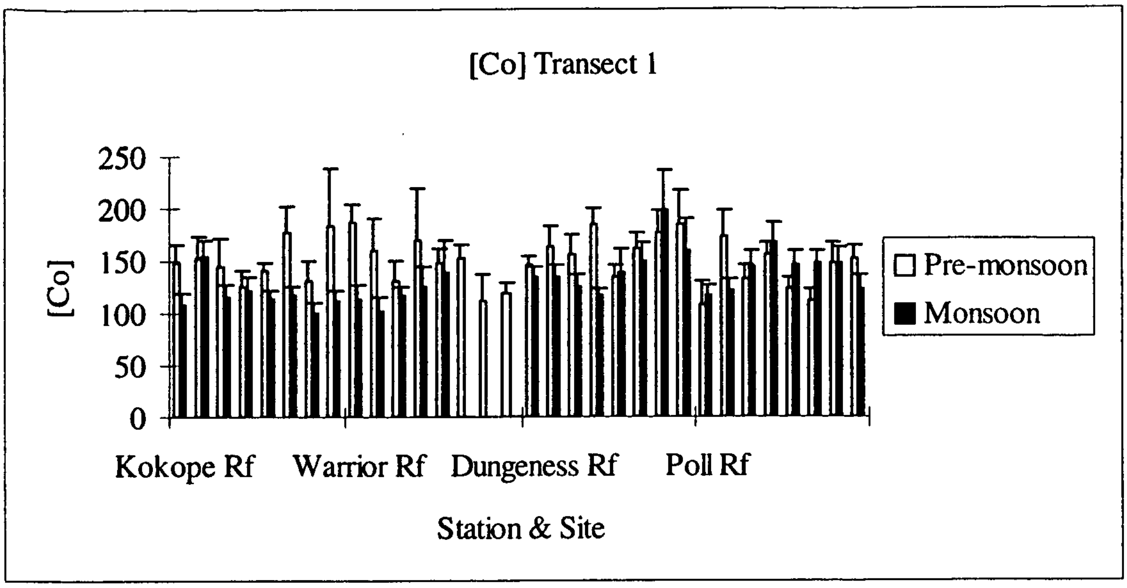
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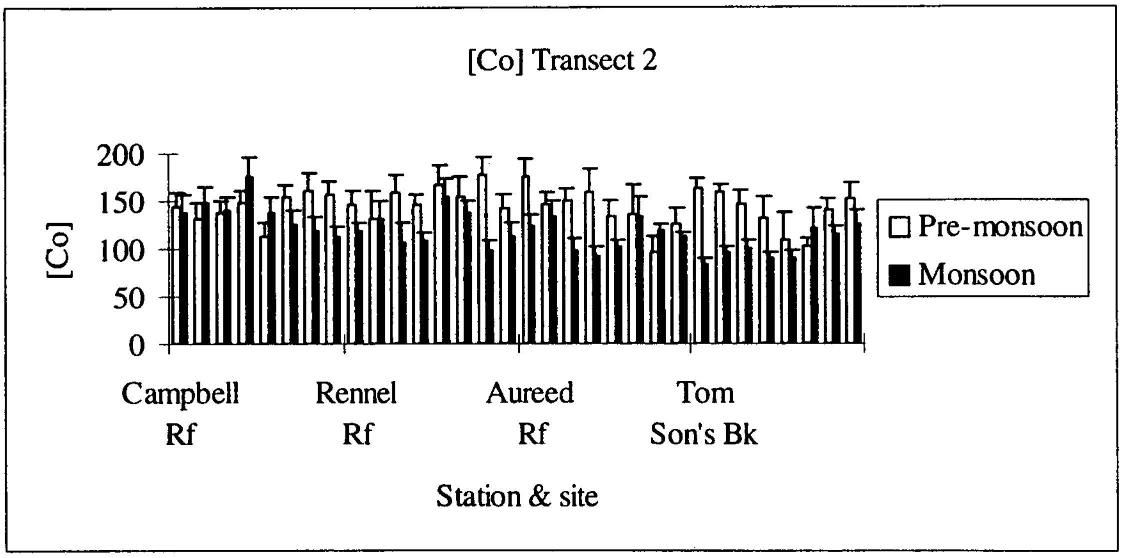
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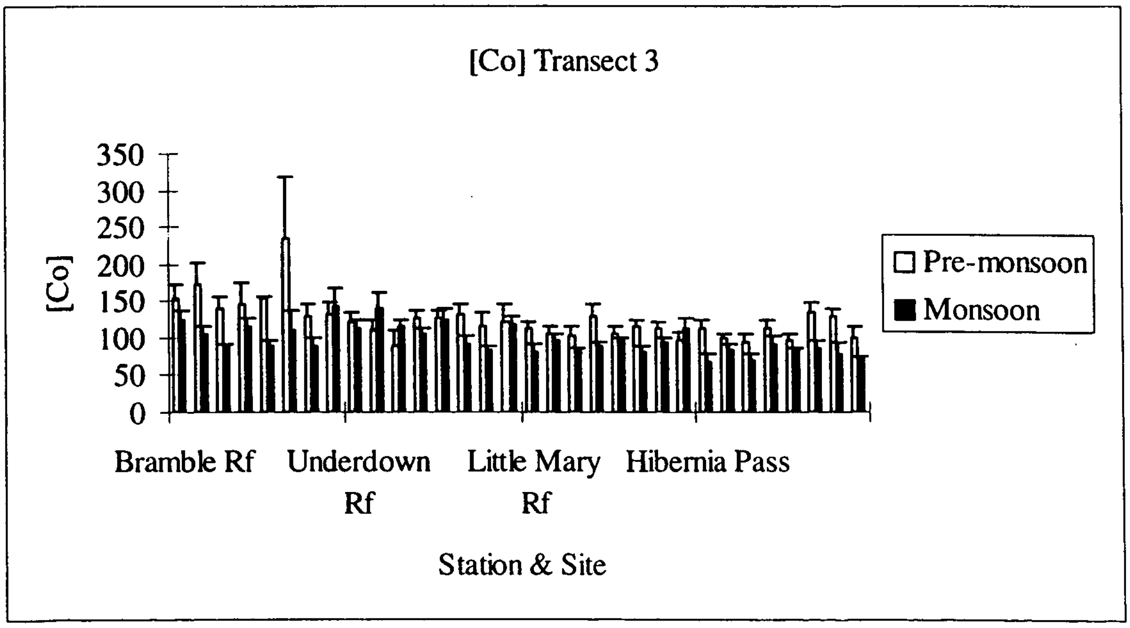
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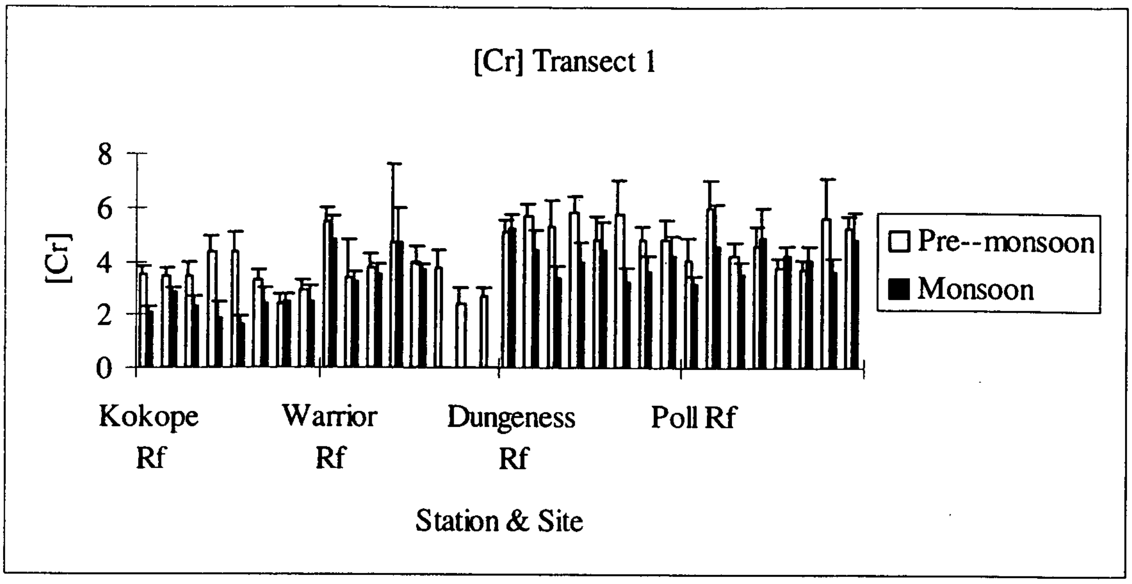
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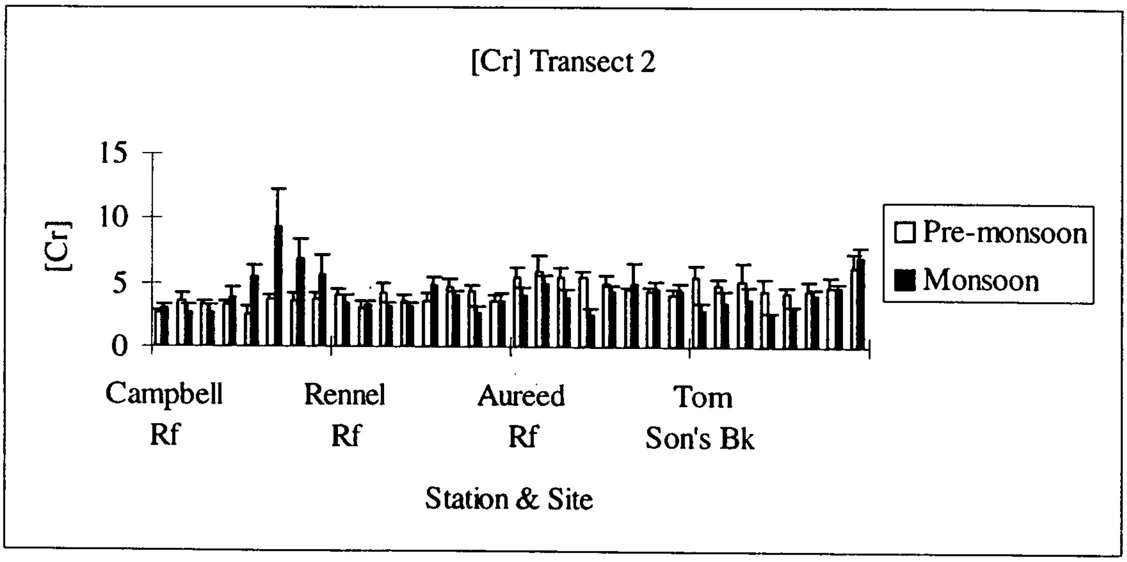
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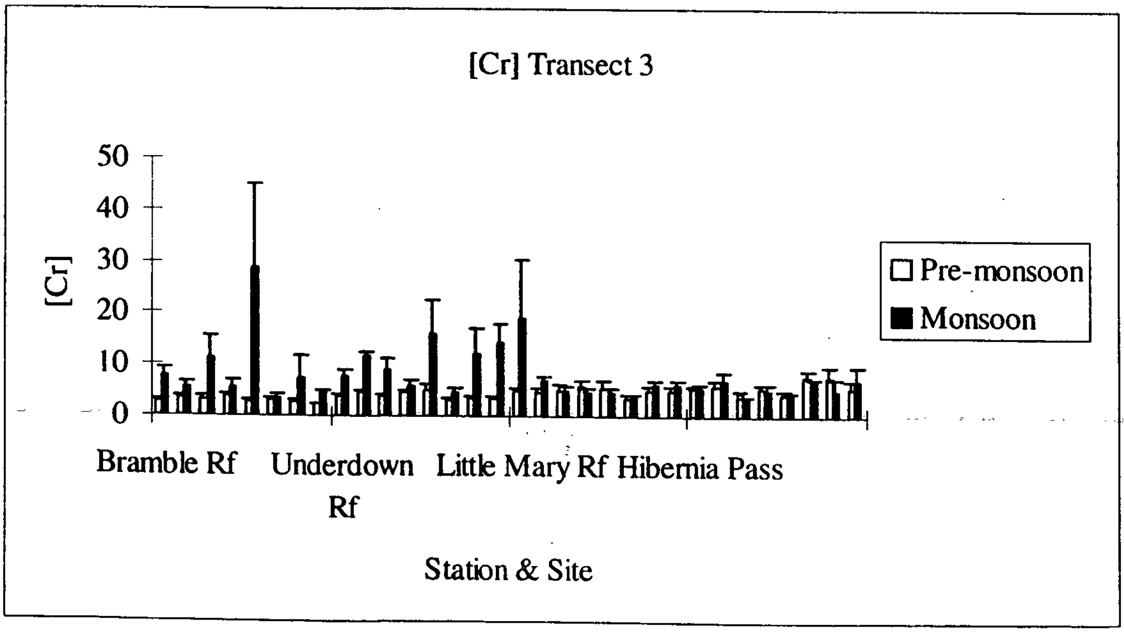
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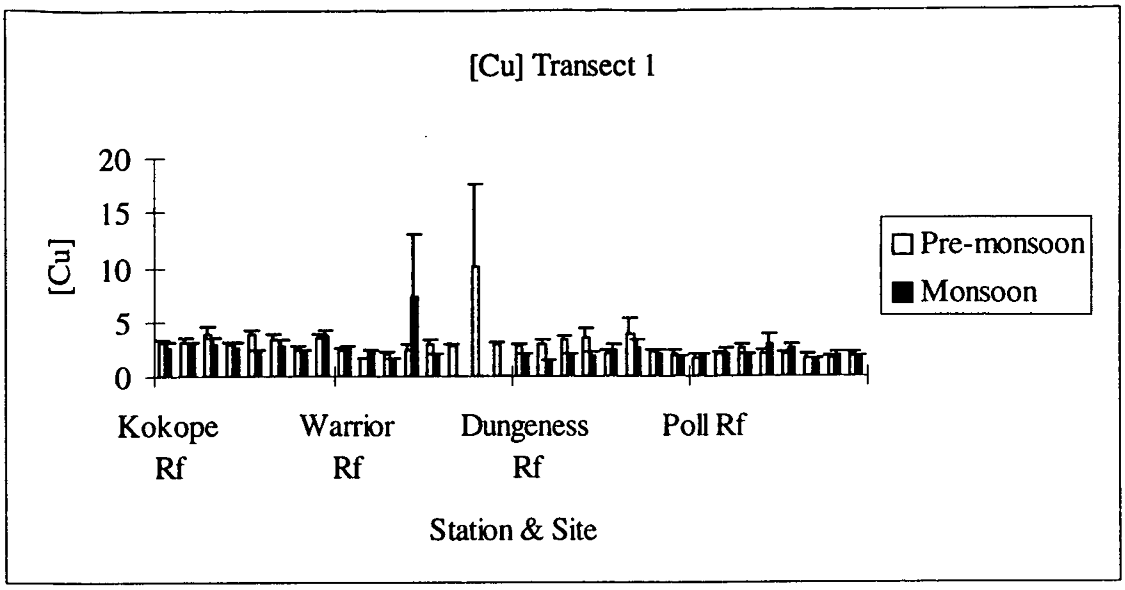
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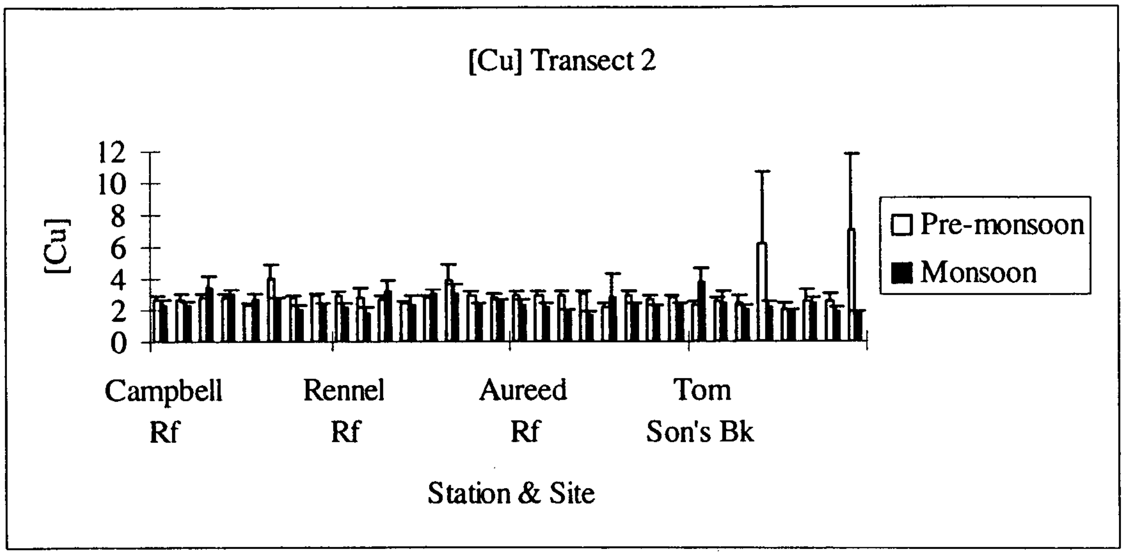
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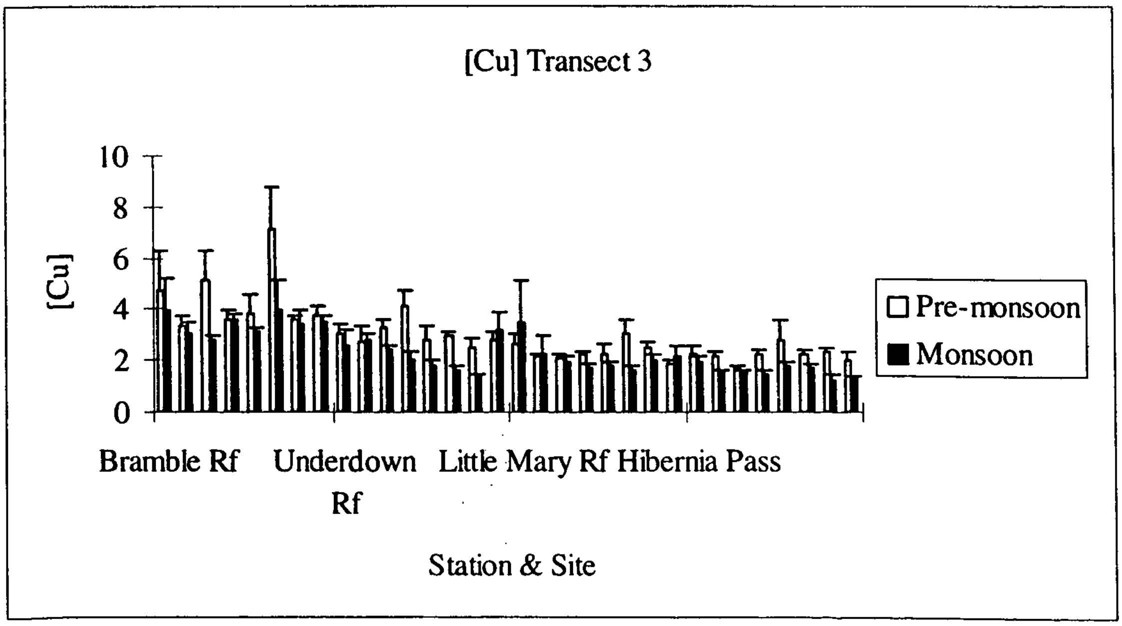
Station & Site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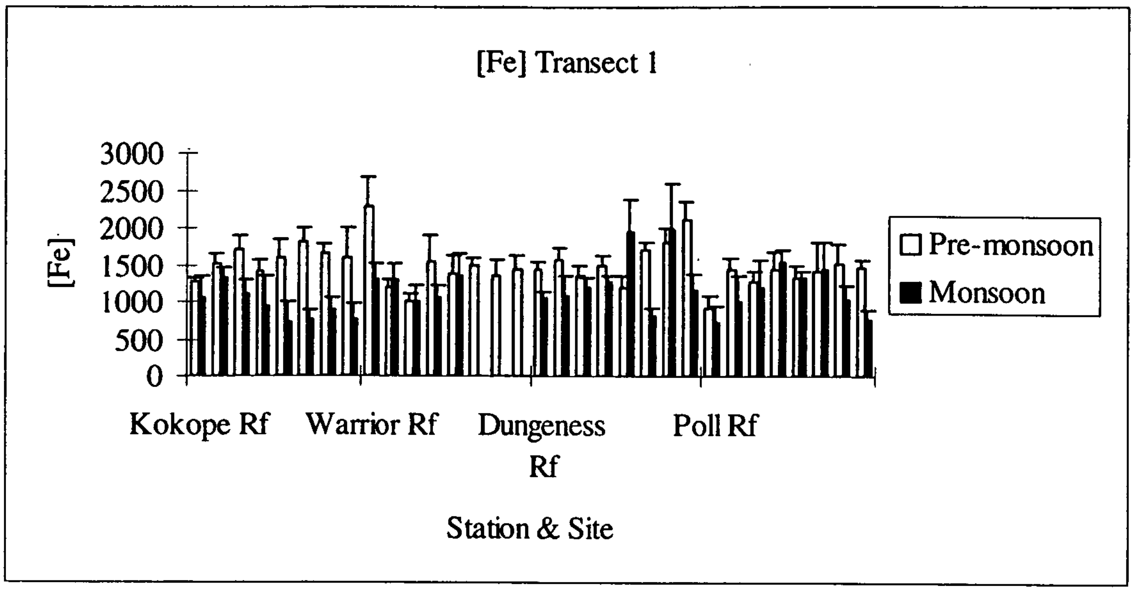
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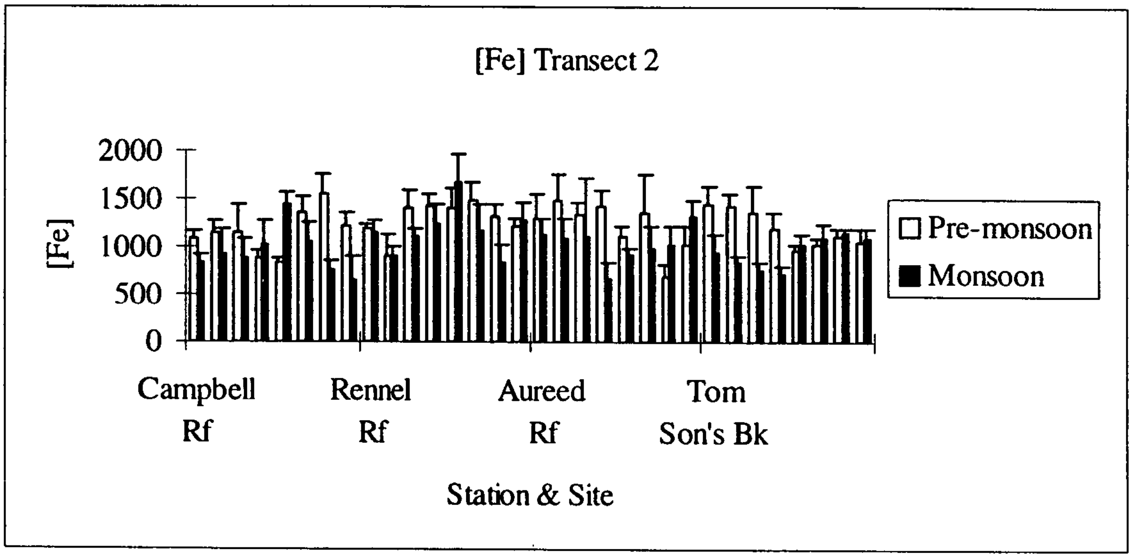
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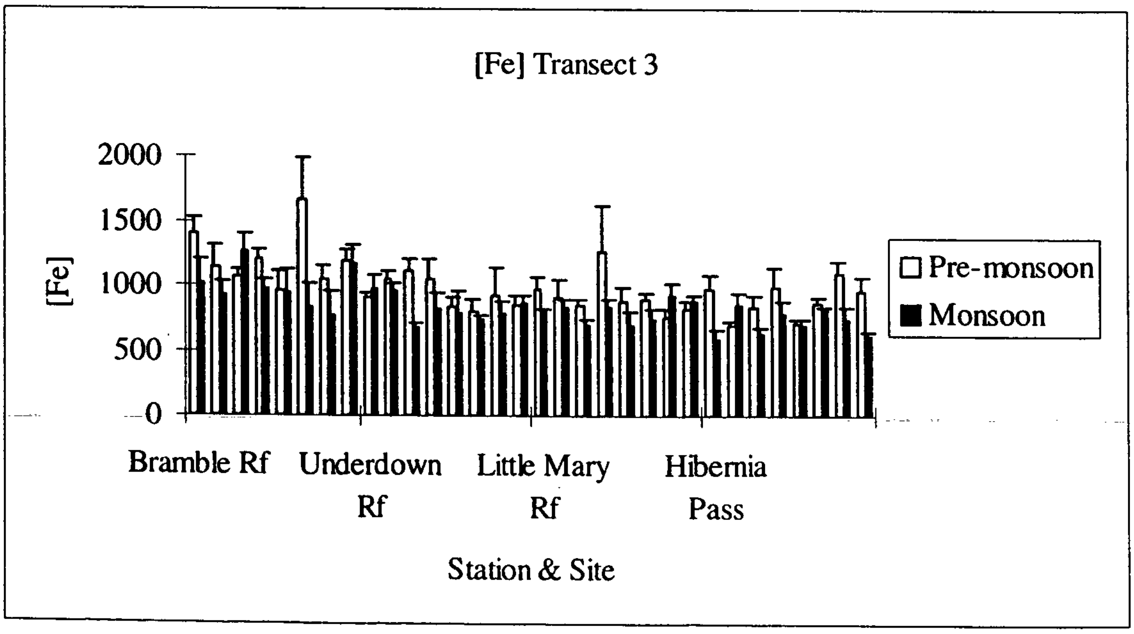
Station & Site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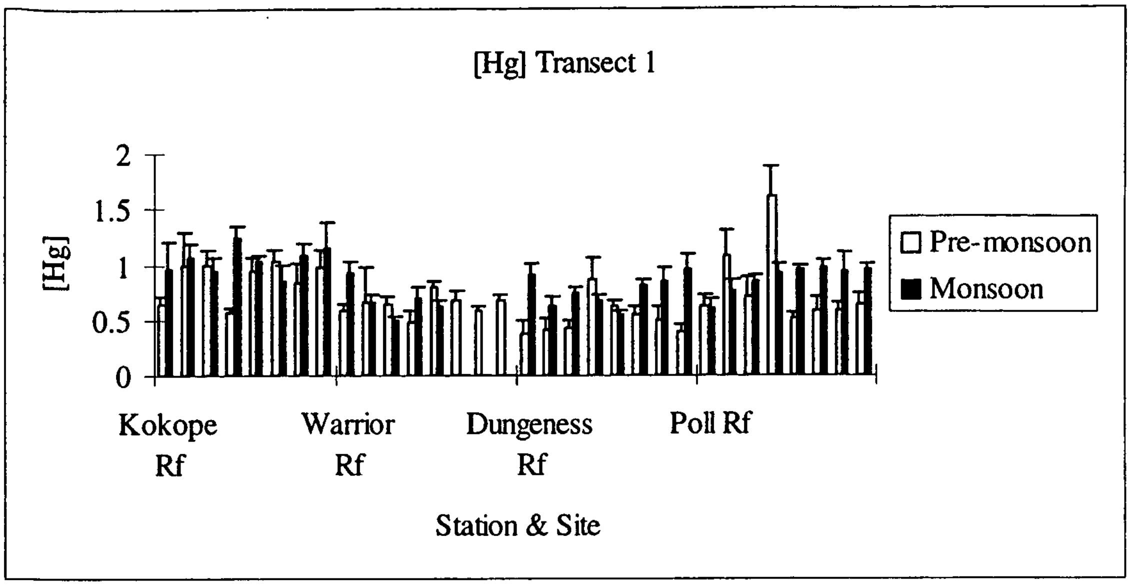
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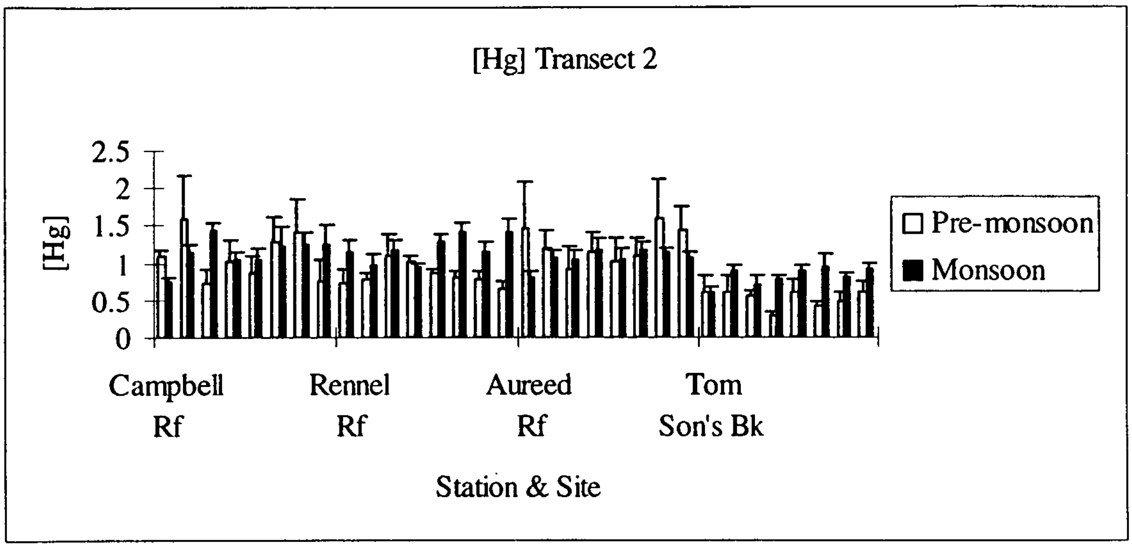
Station & Site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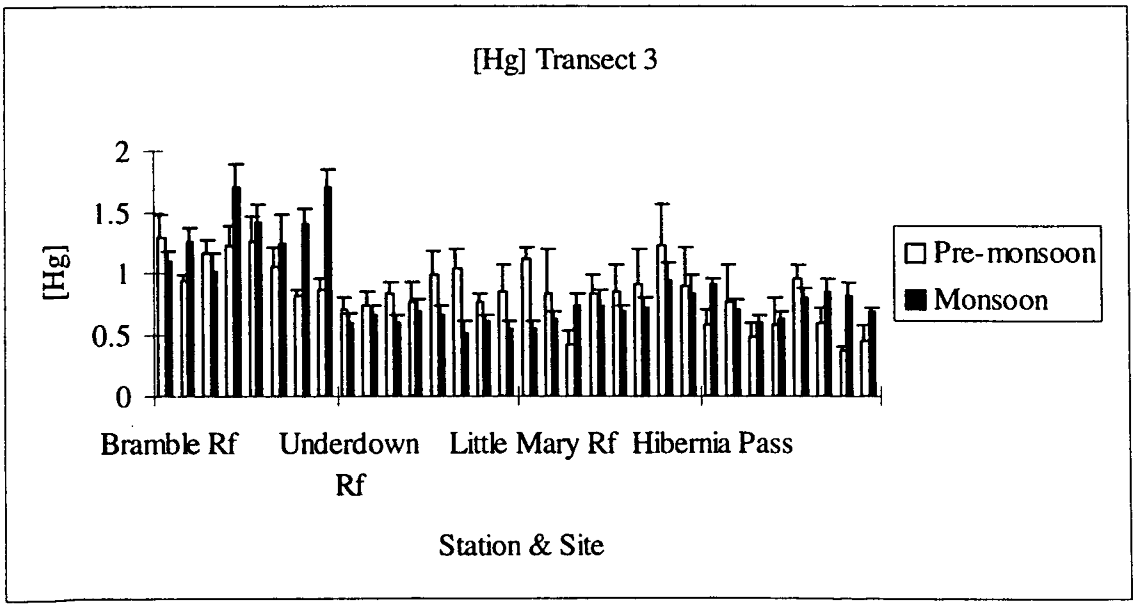
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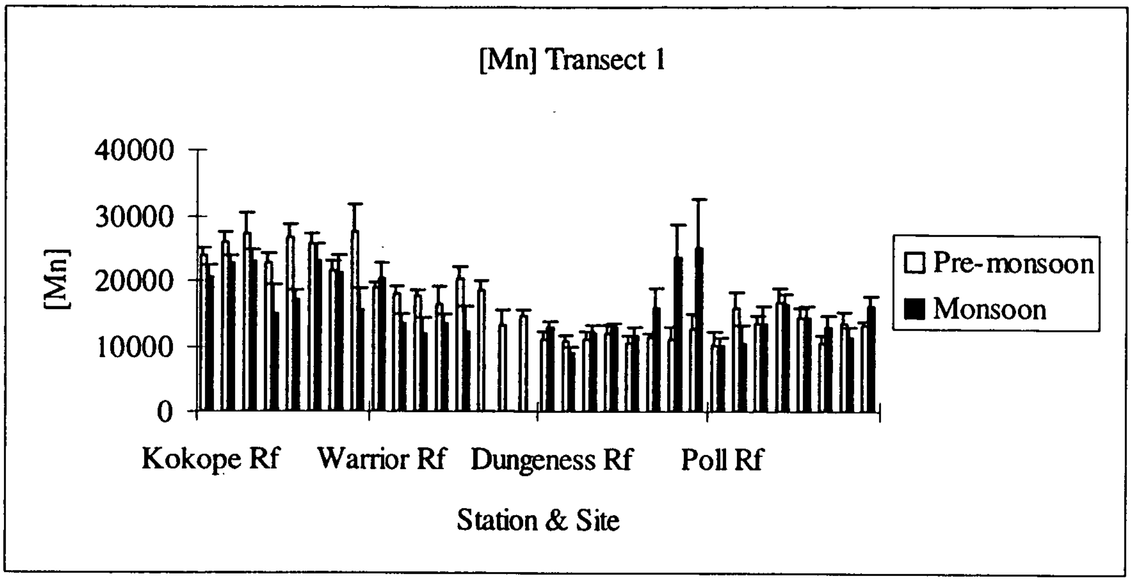
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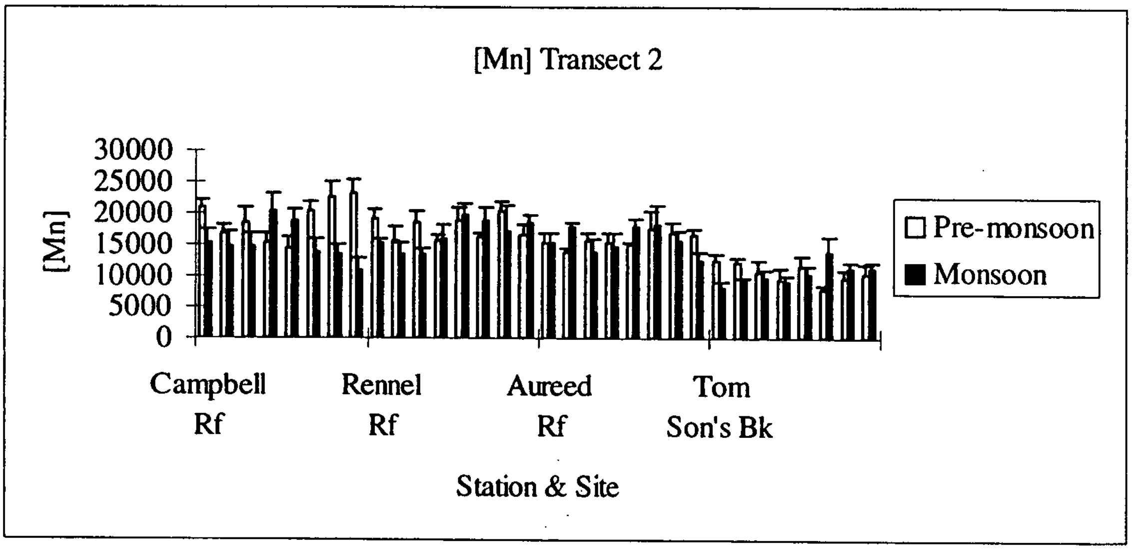
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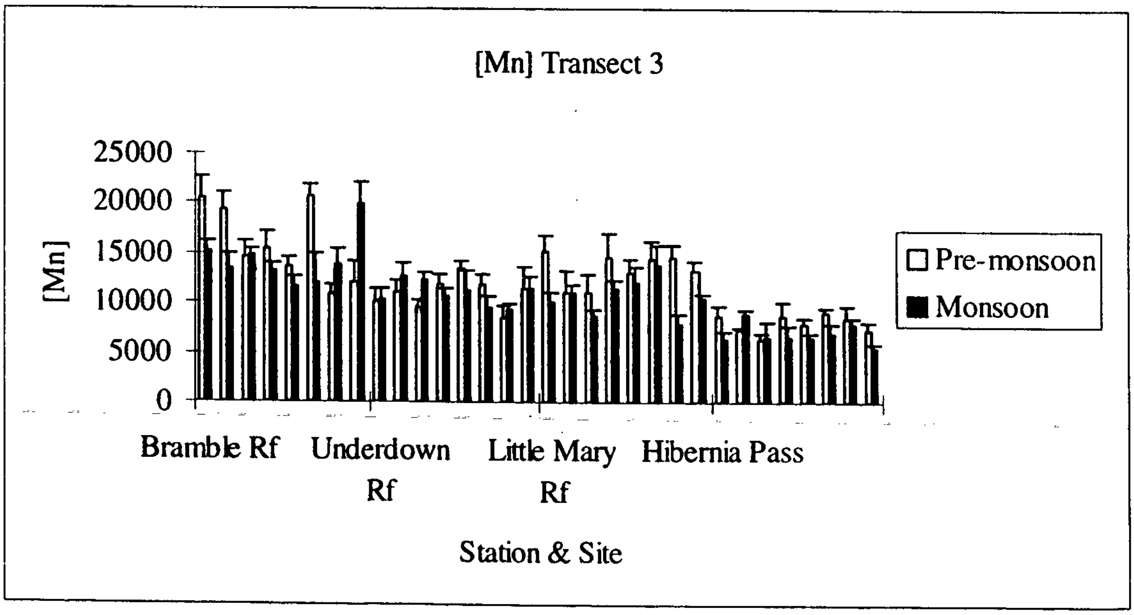
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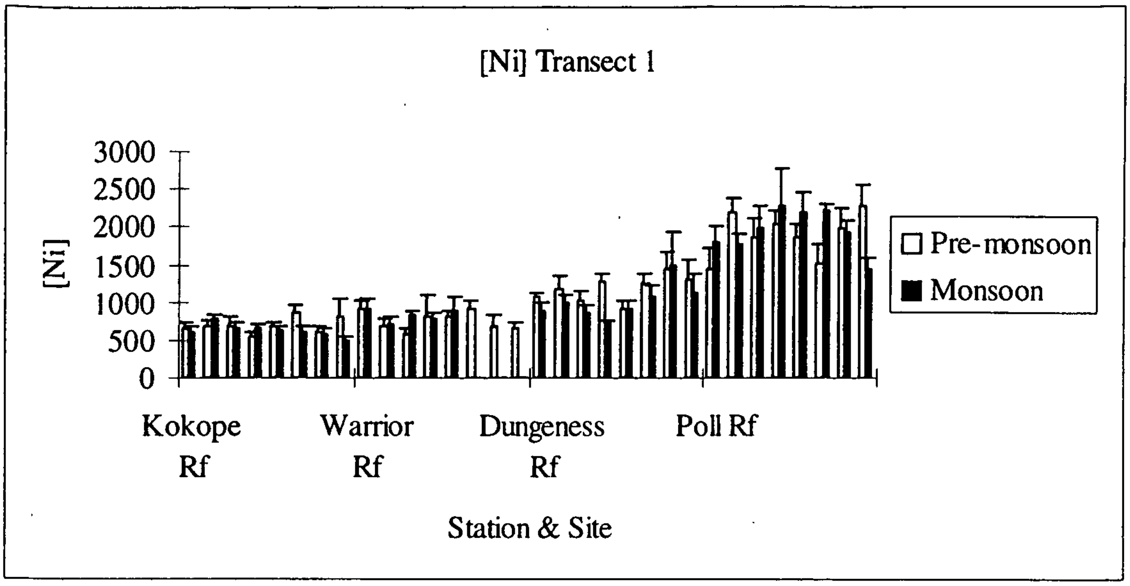
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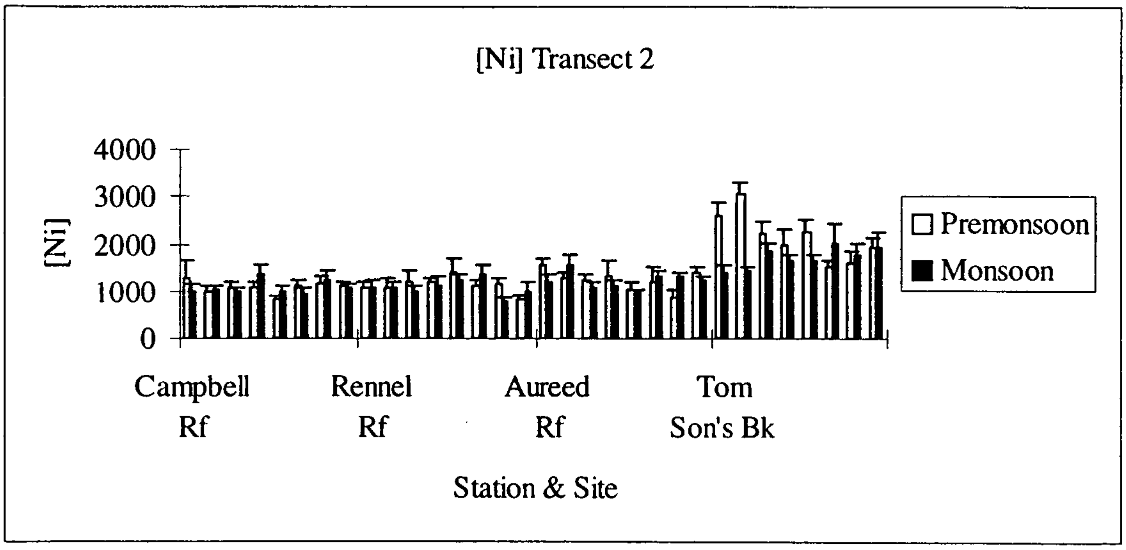
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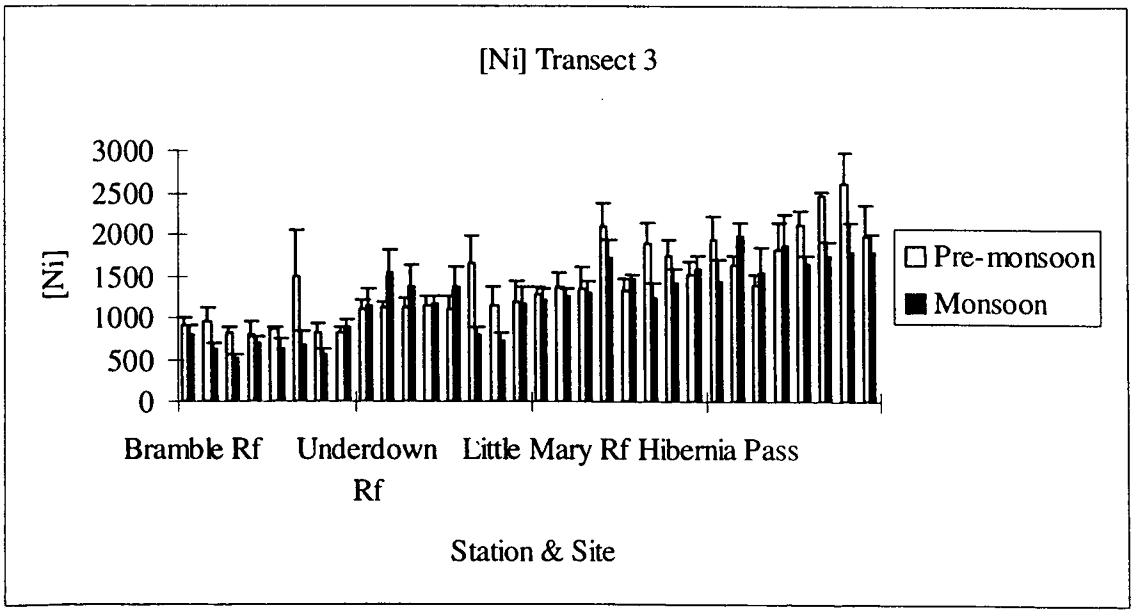
Station & Site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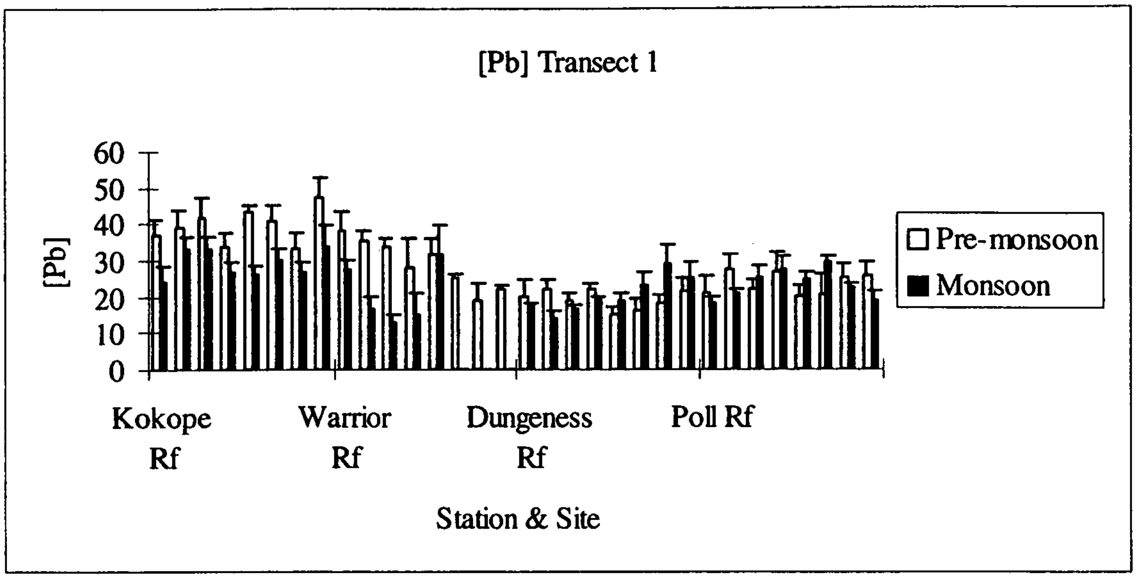
Station & Site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Station & Site
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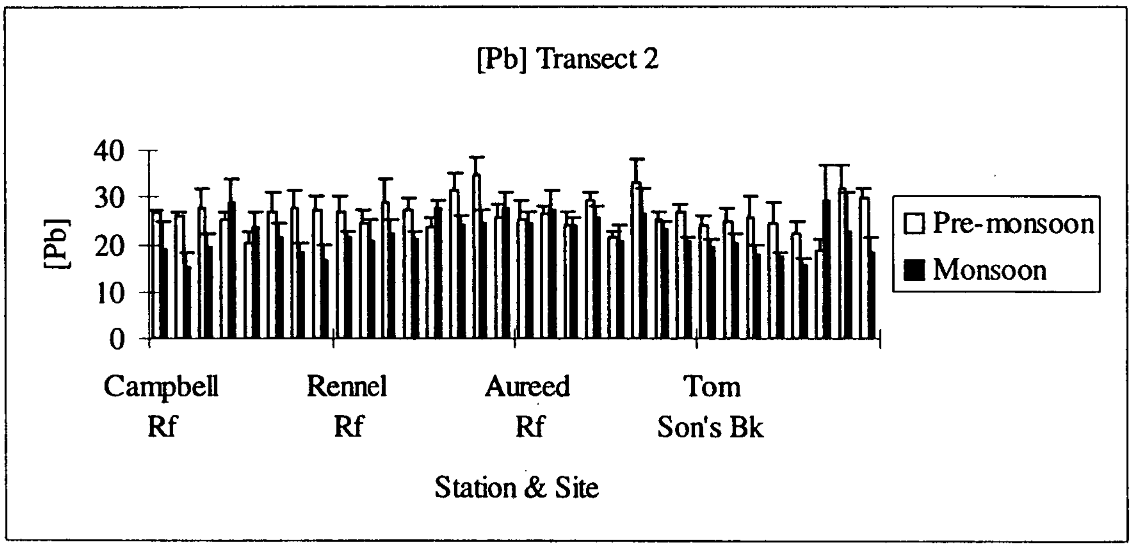
Monsoon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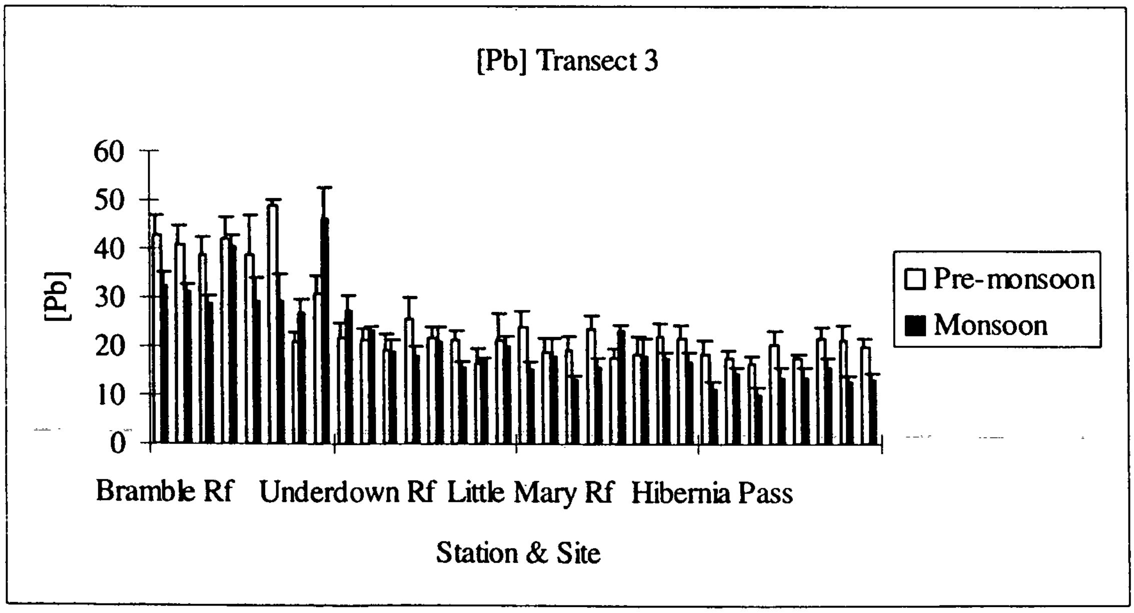
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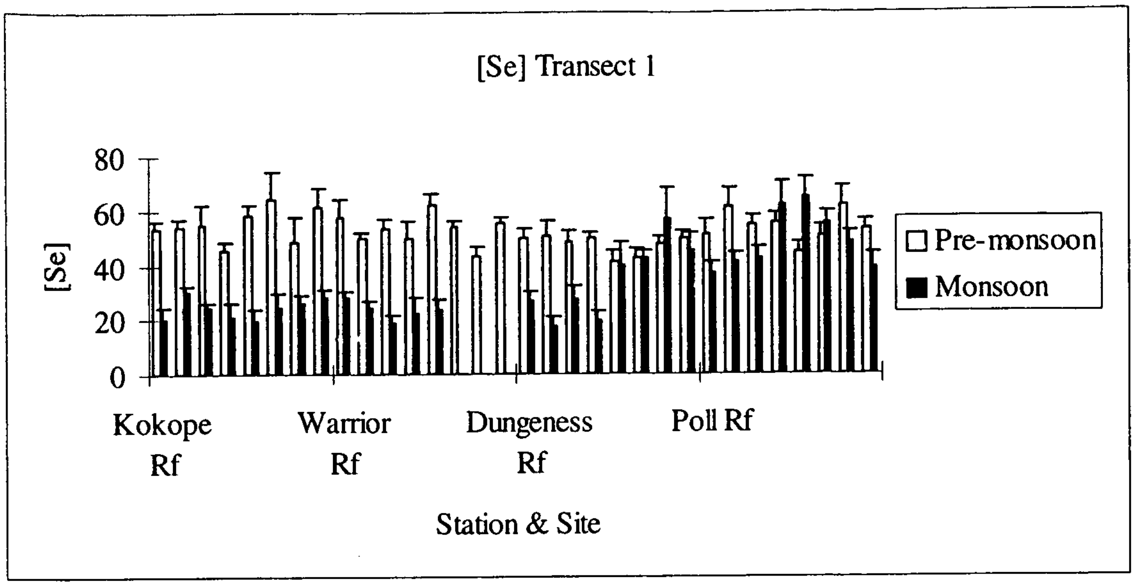
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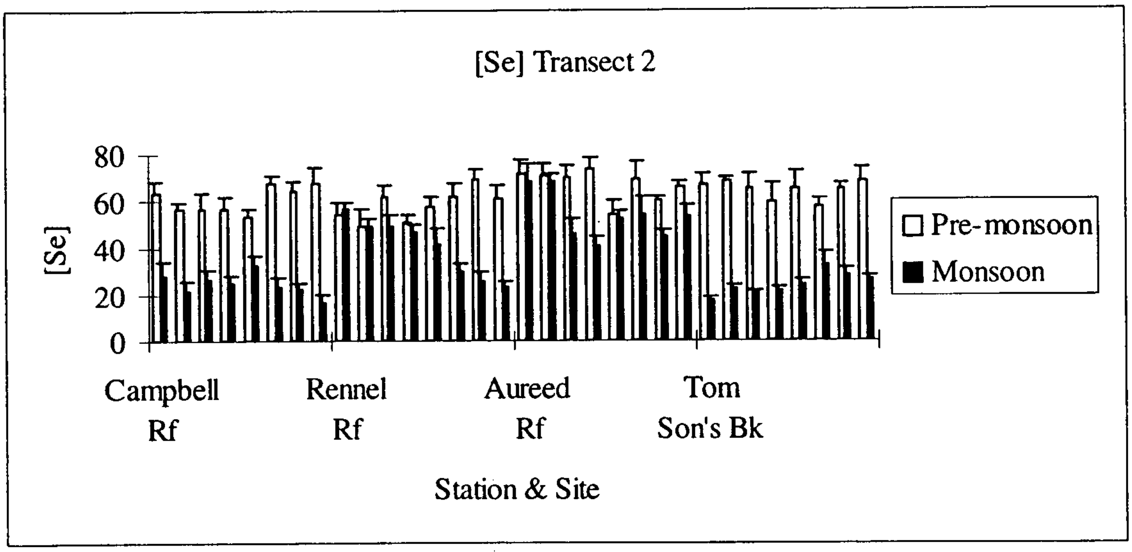
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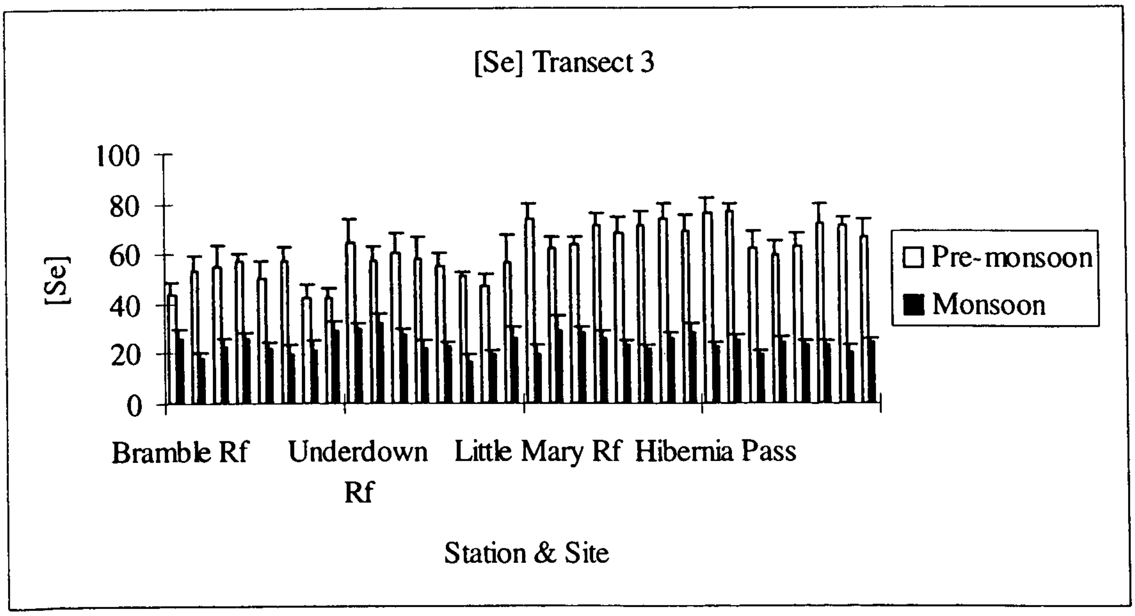
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Station & Site
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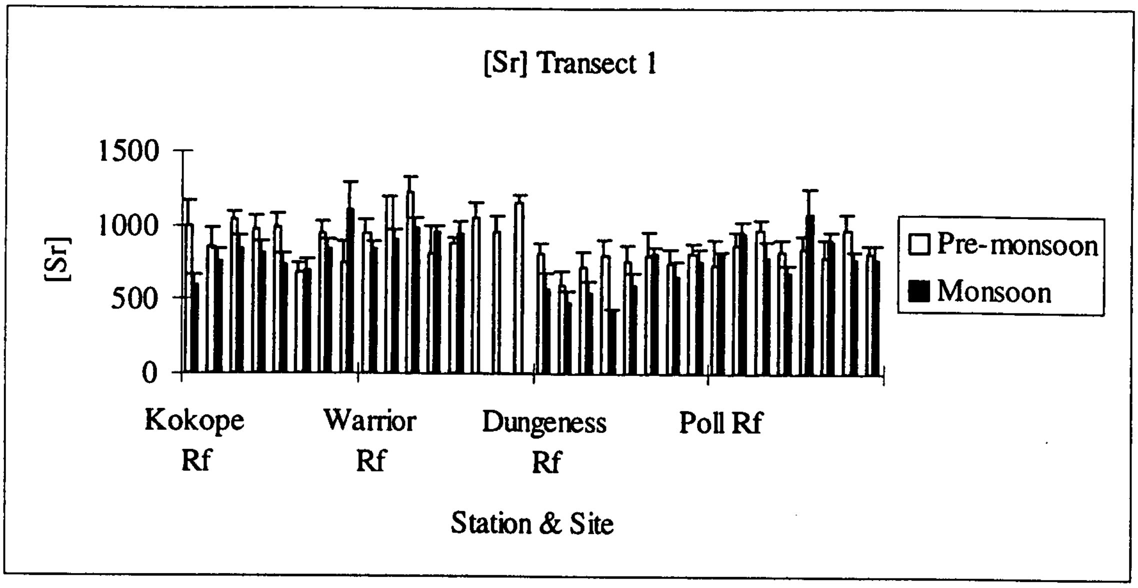
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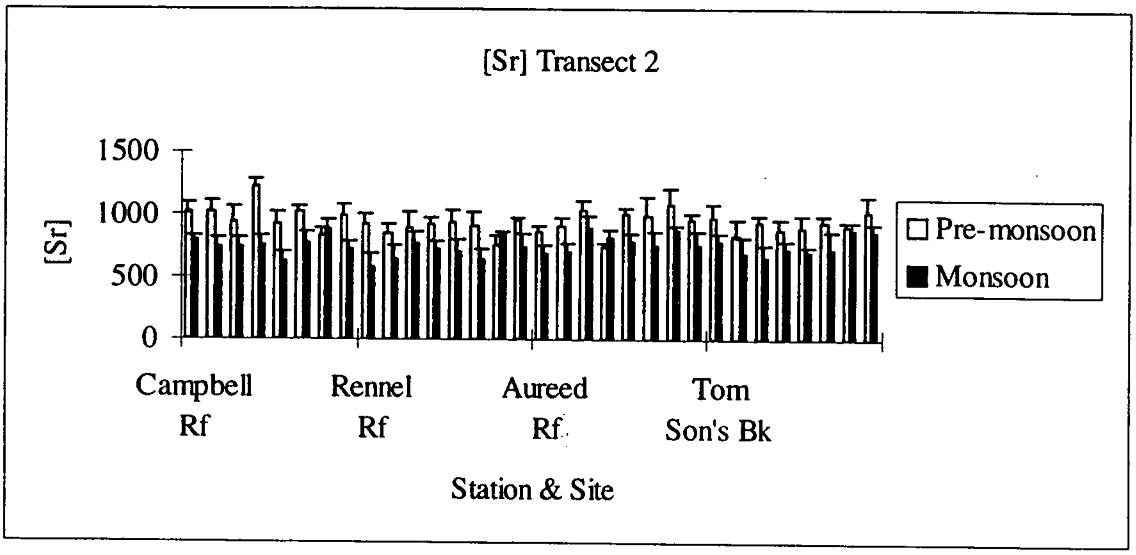
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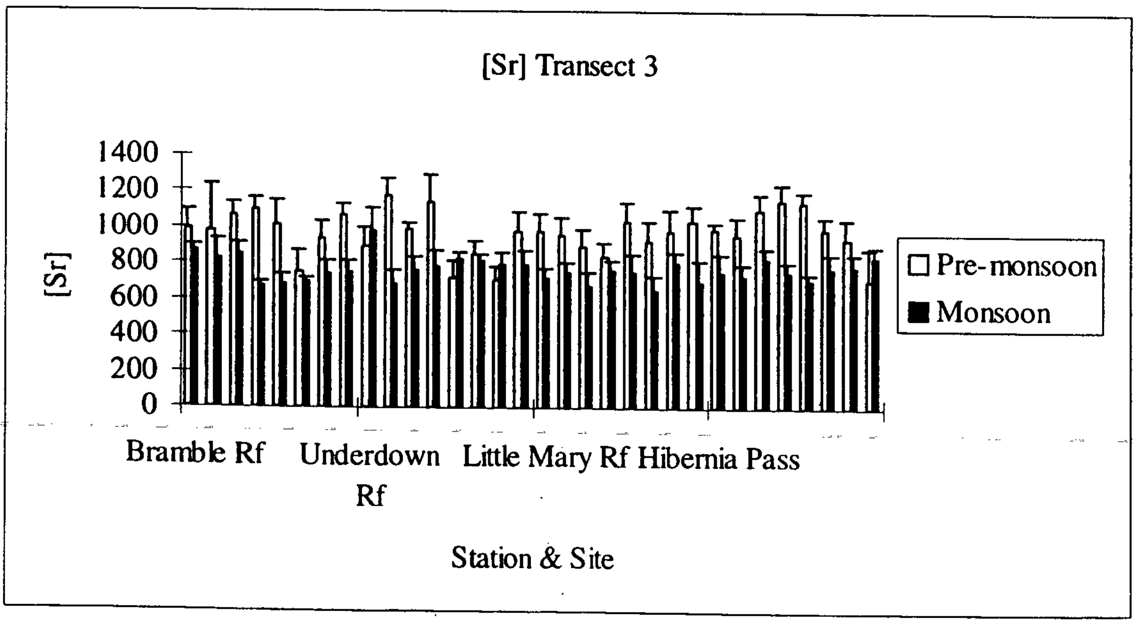
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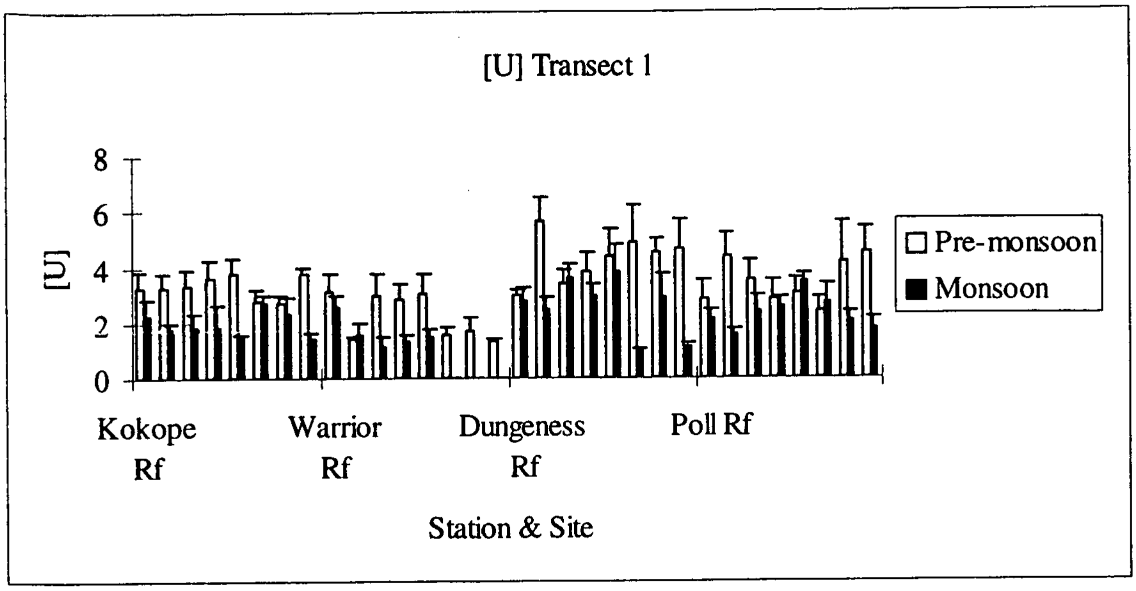
Station & Site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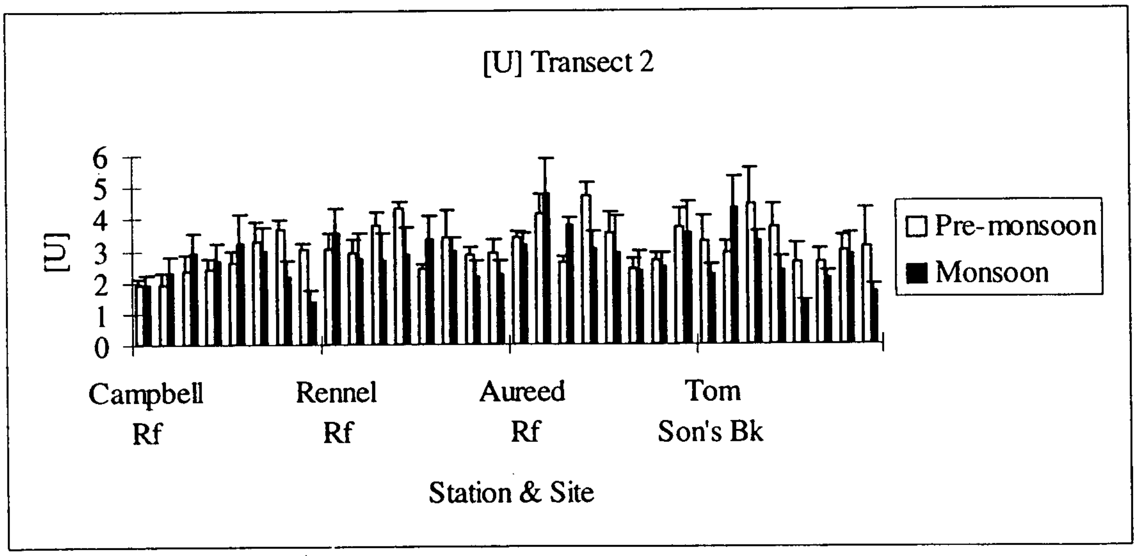
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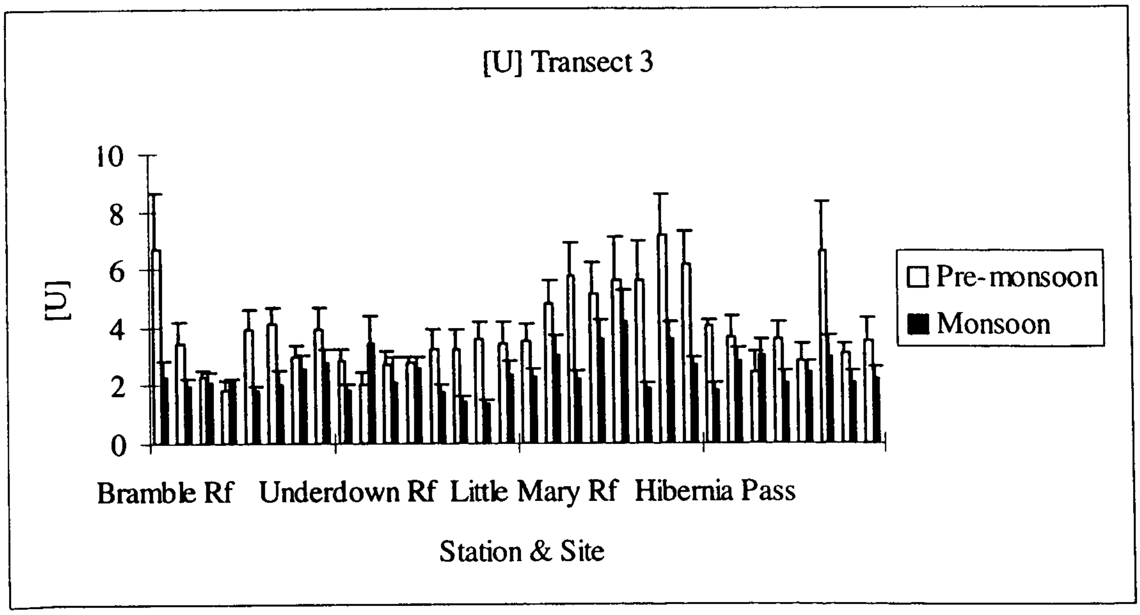
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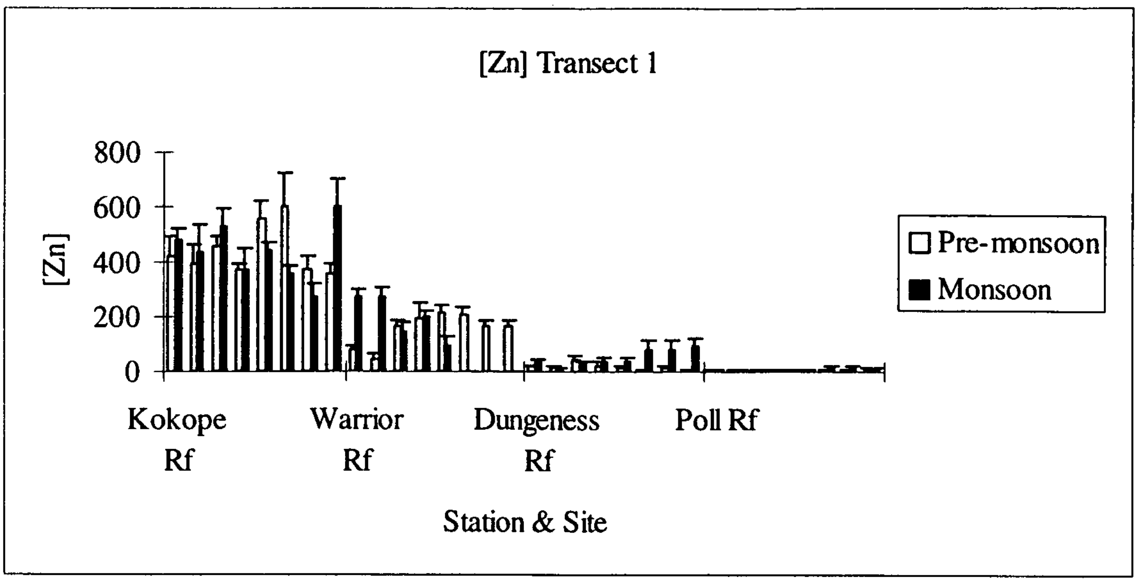

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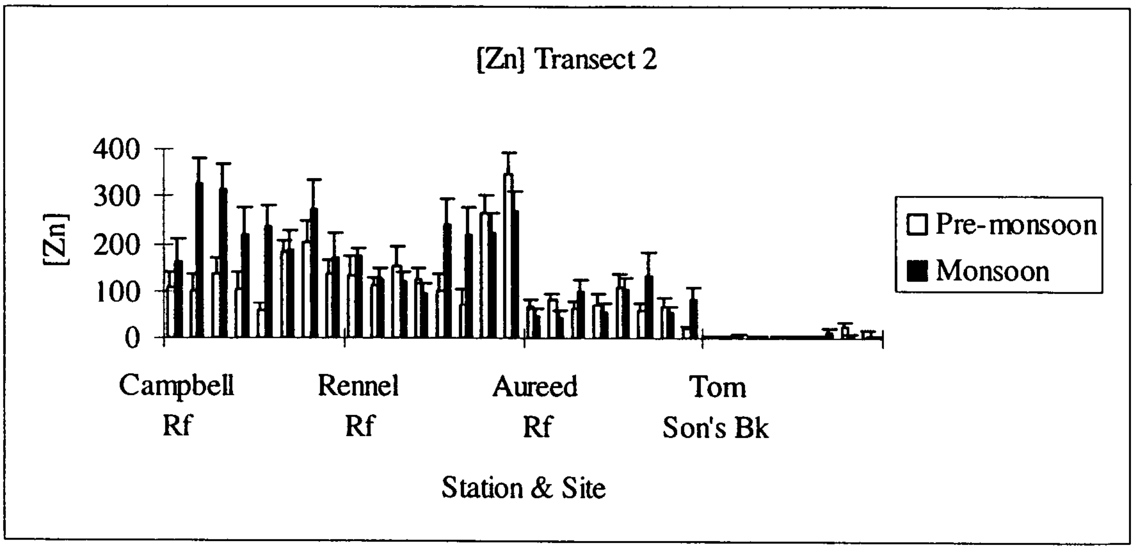

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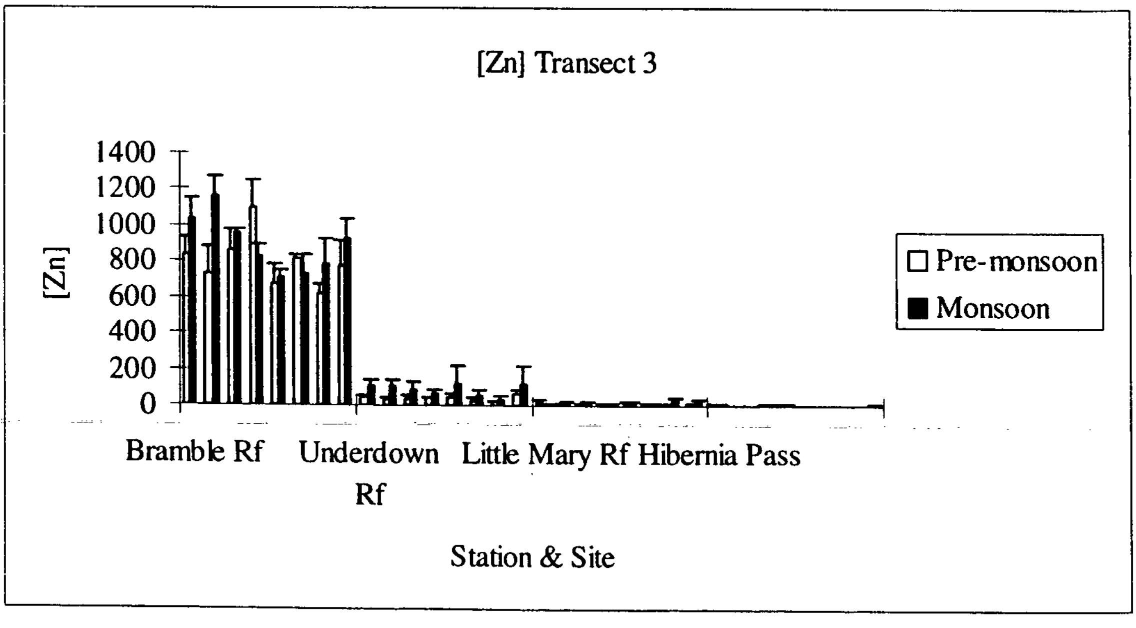
Station & Site



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Pre-monsoon
Monsoon
Bramble Rf
Underdown Rf
Little Mary Rf
Hibernia Pass
Station & Site

Formulae used for the calculation of F ratios and variance components for analysis of variance of burrowing clam trace metal data.

F ratios

Factor	F ratio
Season	$F_{season} = MS_{season}/MS_{site}$
Station	$F_{station} = MS_{station}/MS_{site}$
Season X Station	$F_{season\ X\ station} = MS_{seasonxstation}/MS_{site}$
Site(Season X Station)	$F_{site} = MS_{site}/MS_{residual}$
Residual	
Total	

Variance Components

Season = $(MS_{season} - MS_{site})/N$ where N=480 (i.e. 12 stations X 8 sites X 5 reps)

Station = $(MS_{station} - MS_{site})/N$ where N=80 (i.e. 2 seasons X 8 sites X 5 reps)

Season X Station = $(MS_{season\ x\ station} - MS_{site})/N$ where N=40 (i.e. 8 sites X 5 reps)

Site = $(MS_{site} - MS_{residual})/N$ where N=5 (i.e. 5 reps)

Residual = $MS_{residual}$

Analysis of variance (ANOVA) tables comparing the effects of season (pre-monsoon and monsoon), station and site on trace metal levels in the burrowing clam (*T. crocea*) from the Torres Strait. Metal levels were transformed to natural logs prior to analysis. Sampling design is explained in the text. Formulae used for the calculation of F ratios are shown in table 2.1. Sources of variation are significant when their p value is less than the adjusted alpha significance level of $p = 0.003$ (see table 2.2).

Silver

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	5.678	5.678	0.24	2.18	0.14
Station	11	779.664	70.879	31.97	27.23	<0.0001
Season*Station	11	51.792	4.708	1.97	1.81	0.06
Site(Season*Station)	165	429.555	2.603	7.92	1.68	<0.0001
Residual	742	1146.831	1.546	57.91		
Total	930	2413.559				

Aluminium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	35.482	35.482	6.62	37.96	<0.0001
Station	11	150.523	13.683	14.65	14.64	<0.0001
Season*Station	11	89.153	8.104	16.47	8.60	<0.0001
Site(Season*Station)	165	154.245	0.935	5.92	1.53	0.0001
Residual	742	454.747	0.613	56.34		
Total	930	890.181				

Arsenic

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	0.003	0.003	0	0.02	0.89
Station	11	19.016	1.729	15.05	12.93	<0.0001
Season*Station	11	1.880	0.171	0.70	1.28	0.24
Site(Season*Station)	165	22.058	0.134	4.23	1.26	0.02
Residual	742	78.747	0.106	80.02		
Total	930	121.754				

Cadmium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	0.108	0.108	0	0.17	0.68
Station	11	364.098	33.100	43.88	52.28	<0.0001
Season*Station	11	13.877	1.262	1.70	1.99	0.03
Site(Season*Station)	165	104.472	0.633	3.50	1.35	0.005
Residual	742	349.126	0.471	50.92		
Total	930	835.035				

Cobalt

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	7.199	7.199	11.39	63.87	<0.0001
Station	11	17.338	1.576	14.11	13.98	<0.0001
Season*Station	11	3.173	0.288	3.38	2.54	0.006
Site(Season*Station)	165	18.598	0.113	4.01	1.29	0.01
Residual	742	64.666	0.087	67.12		
Total	930	110.758				

Chromium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	0.333	0.333	0.04	1.21	0.27
Station	11	38.118	3.465	13.23	12.61	<0.0001
Season*Station	11	31.883	2.898	21.76	10.54	<0.0001
Site(Season*Station)	165	45.355	0.275	6.57	1.56	<0.0001
Residual	742	130.587	0.176	58.40		
Total	930	246.732				

Copper

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	9.589	9.589	10.24	63.93	<0.0001
Station	11	29.412	2.674	16.43	17.83	<0.0001
Season*Station	11	2.519	0.229	1.03	1.53	0.12
Site(Season*Station)	165	24.748	0.150	1.46	1.10	0.21
Residual	742	101.223	0.136	70.84		
Total	930	167.021				

Iron

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	14.225	14.225	13.74	69.54	<0.0001
Station	11	21.596	1.963	10.33	9.60	<0.0001
Season*Station	11	4.216	0.383	2.09	1.87	0.05
Site(Season*Station)	165	33.752	0.205	5.65	1.41	0.002
Residual	742	107.739	0.145	68.19		
Total	930	182.345				

Mercury

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	11.266	11.266	7.23	43.90	<0.0001
Station	11	52.975	4.816	17.95	18.77	<0.0001
Season*Station	11	12.541	1.140	6.95	4.44	0.0001
Site(Season*Station)	165	42.340	0.257	3.28	1.25	0.03
Residual	742	152.412	0.205	64.59		
Total	930	272.859				

Manganese

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	2.472	2.472	2.52	15.96	0.0001
Station	11	70.570	6.415	40.84	41.44	<0.0001
Season*Station	11	4.836	0.440	3.72	2.84	0.002
Site(Season*Station)	165	25.547	0.155	6.99	1.76	<0.0001
Residual	742	65.408	0.088	45.93		
Total	930	169.122				

Nickel

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	1.455	1.455	1.20	11.10	0.001
Station	11	108.805	9.891	53.01	75.43	<0.0001
Season*Station	11	2.843	0.258	1.38	1.97	0.03
Site(Season*Station)	165	21.637	0.131	3.13	1.38	0.003
Residual	742	70.546	0.095	41.28		
Total	930	207.666				

Lead

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	7.796	7.796	8.83	51.55	<0.0001
Station	11	45.164	4.106	27.41	27.15	<0.0001
Season*Station	11	5.535	0.503	4.88	3.33	0.0004
Site(Season*Station)	165	24.953	0.151	6.21	1.59	<0.0001
Residual	742	70.550	0.095	52.67		
Total	930	152.890				

Selenium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	119.636	119.636	60.22	790.43	<0.0001
Station	11	25.514	2.319	6.56	15.32	<0.0001
Season*Station	11	23.448	2.132	11.98	14.12	<0.0001
Site(Season*Station)	165	24.974	0.151	3.82	2.10	<0.0001
Residual	742	53.369	0.072	17.42		
Total	930	247.379				

Strontium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	7.956	7.956	16.31	81.82	<0.0001
Station	11	6.460	0.587	6.18	6.56	<0.0001
Season*Station	11	1.638	0.149	1.47	1.66	0.09
Site(Season*Station)	165	14.780	0.090	3.38	1.23	0.04
Residual	742	54.069	0.073	72.65		
Total	930	85.359				

Uranium

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	31.942	31.942	19.55	94.16	<0.0001
Station	11	27.626	2.511	8.06	7.40	<0.0001
Season*Station	11	6.188	0.563	1.66	1.66	0.09
Site(Season*Station)	165	55.974	0.339	7.48	1.59	<0.0001
Residual	742	157.870	0.213	63.24		
Total	930	279.755				

Zinc

Source of variation	df	SS	MS	% of total variation	F	p
Season	1	25.518	25.518	1.28	22.32	<0.0001
Station	11	2767.946	251.631	78.67	220.05	<0.0001
Season*Station	11	16.257	1.478	0.21	1.29	0.23
Site(Season*Station)	165	188.679	1.144	2.23	1.63	0.0001
Residual	742	520.349	0.701	17.61		
Total	930	3554.759				

Results of a comparison, among stations in each season, of the mean levels of each metal by Tukey's HSD test (analysis of variance indicated significant station effects for all metals in both seasons). Stations with the same letter are not significantly different at the 5% level. Station means are ranked vertically in each season from highest to lowest; actual values are shown in appendix 8. Locations of stations are shown in figure 2.1.

Metal	Pre-Monsoon	Monsoon
Silver	Kokope Reef (a)	Kokope Reef (a)
	Warrior Reef (b)	Warrior Reef (b)
	Bramble Reef (bc)	Underdown Reef (bc)
	Hibernia Passage (bcd)	Bramble Reef (c)
	Dungeness Reef (cde)	Rennel Reef (c)
	Rennel Reef (e)	Dungeness Reef (c)
	Little Mary Reef (e)	Aureed Reef (c)
	Aureed Reef (e)	Campbell Reef (c)
	Underdown Reef (e)	Tom Son's Bank (c)
	Poll Reef (e)	Little Mary Reef (c)
	Tom Son's Bank (e)	Hibernia Passage (c)
	Campbell Reef (e)	Poll Reef (c)
Aluminium	Poll Reef (a)	Bramble Reef (a)
	Kokope Reef (ab)	Little Mary Reef (b)
	Dungeness Reef (abc)	Underdown Reef (c)
	Rennel Reef (abcd)	Kokope Reef (c)
	Bramble Reef (abcde)	Poll Reef (cd)
	Underdown Reef (bcdef)	Campbell Reef (cd)
	Aureed Reef (defg)	Warrior Reef (cd)
	Tom Son's Bank (defgh)	Rennel Reef (cd)
	Warrior Reef (defgh)	Dungeness Reef (cd)
	Little Mary Reef (efgh)	Aureed Reef (de)
	Campbell Reef (efgh)	Tom Son's Bank (de)
	Hibernia Passage (h)	Hibernia Passage (e)
Arsenic	Dungeness Reef (a)	Warrior Reef (a)
	Kokope Reef (ab)	Dungeness Reef (a)
	Warrior Reef (abc)	Kokope Reef (a)
	Tom Son's Bank (abcd)	Poll Reef (a)
	Campbell Reef (abcde)	Rennel Reef (a)
	Rennel Reef (abcdef)	Campbell Reef (a)
	Aureed Reef (abcdefg)	Tom Son's Bank (ab)
	Poll Reef (abcdefgh)	Aureed Reef (ab)
	Hibernia Passage (bcdefghi)	Bramble Reef (ab)
	Bramble Reef (cdefghi)	Underdown Reef (bc)
	Underdown Reef (i)	Little Mary Reef (c)
	Little Mary Reef (i)	Hibernia Passage (c)

Metal	Pre-Monsoon	Monsoon
Cadmium	Kokope Reef (a)	Kokope Reef (a)
	Warrior Reef (ab)	Warrior Reef (ab)
	Bramble Reef (bc)	Rennel Reef (abc)
	Rennel Reef (bcd)	Dungeness Reef (bcd)
	Dungeness Reef (cde)	Bramble Reef (bcd)
	Campbell Reef (def)	Campbell Reef (cde)
	Aureed Reef (defg)	Poll Reef (de)
	Poll Reef (efgh)	Aureed Reef (efg)
	Underdown Reef (efghi)	Tom Son's Bank (efgh)
	Little Mary Reef (hij)	Underdown Reef (fgh)
	Tom Son's Bank (ij)	Little Mary Reef (h)
	Hibernia Passage (j)	Hibernia Passage (i)
Cobalt	Dungeness Reef (a)	Dungeness Reef (a)
	Rennel Reef (a)	Poll Reef (a)
	Bramble Reef (a)	Campbell Reef (ab)
	Kokope Reef (a)	Rennel Reef (abc)
	Campbell Reef (a)	Kokope Reef (abc)
	Warrior Reef (ab)	Warrior Reef (abc)
	Aureed Reef (abc)	Aureed Reef (bc)
	Poll Reef (abc)	Underdown Reef (cd)
	Tom Son's Bank (abc)	Bramble Reef (cd)
	Underdown Reef (bc)	Tom Son's Bank (cd)
	Little Mary Reef (bc)	Little Mary Reef (de)
	Hibernia Passage (c)	Hibernia Passage (e)
Chromium	Hibernia Passage (a)	Underdown Reef (a)
	Dungeness Reef (a)	Bramble Reef (ab)
	Aureed Reef (ab)	Little Mary Reef (bc)
	Little Mary Reef (abc)	Hibernia Passage (bcd)
	Tom Son's Bank (abc)	Campbell Reef (cde)
	Poll Reef (abcd)	Aureed Reef (de)
	Underdown Reef (bcde)	Warrior Reef (de)
	Rennel Reef (cdef)	Dungeness Reef (de)
	Warrior Reef (def)	Poll Reef (de)
	Kokope Reef (ef)	Tom Son's Bank (de)
	Campbell Reef (ef)	Rennel Reef (e)
	Bramble Reef (f)	Kokope Reef (f)
Copper	Bramble Reef (a)	Bramble Reef (a)
	Kokope Reef (ab)	Kokope Reef (ab)
	Underdown Reef (bc)	Campbell Reef (abc)
	Rennel Reef (bcd)	Rennel Reef (bcd)
	Campbell Reef (bcd)	Warrior Reef (bcd)
	Aureed Reef (bcd)	Underdown Reef (bcd)
	Warrior Reef (bcd)	Tom Son's Bank (bcd)
	Dungeness Reef (bcd)	Aureed Reef (bcd)
	Tom Son's Bank (cde)	Little Mary Reef (cde)
	Little Mary Reef (cde)	Poll Reef (cde)
	Hibernia Passage (de)	Dungeness Reef (de)
	Poll Reef (e)	Hibernia Passage (e)

Metal	Pre-Monsoon	Monsoon
Iron	Dungeness Reef (a)	Dungeness Reef (a)
	Kokope Reef (a)	Warrior Reef (ab)
	Warrior Reef (ab)	Rennel Reef (ab)
	Poll Reef (ab)	Poll Reef (abc)
	Rennel Reef (b)	Bramble Reef (abc)
	Bramble Reef (b)	Tom Son's Bank (abc)
	Tom Son's Bank (b)	Aureed Reef (abc)
	Aureed Reef (bc)	Campbell Reef (abc)
	Campbell Reef (bcd)	Underdown Reef (bc)
	Underdown Reef (cde)	Kokope Reef (bc)
	Little Mary Reef (de)	Little Mary Reef (bc)
	Hibernia Passage (e)	Hibernia Passage (c)
Mercury	Bramble Reef (a)	Bramble Reef (a)
	Aureed Reef (a)	Rennel Reef (ab)
	Campbell Reef (ab)	Campbell Reef (ab)
	Kokope Reef (ab)	Aureed Reef (b)
	Rennel Reef (ab)	Kokope Reef (bc)
	Underdown Reef (ab)	Poll Reef (cd)
	Poll Reef (abc)	Tom Son's Bank (de)
	Warrior Reef (bcd)	Dungeness Reef (de)
	Little Mary Reef (bcd)	Hibernia Passage (de)
	Hibernia Passage (cd)	Little Mary Reef (def)
	Tom Son's Bank (d)	Warrior Reef (ef)
	Dungeness Reef (d)	Underdown Reef (f)
Manganese	Kokope Reef (a)	Kokope Reef (a)
	Campbell Reef (b)	Rennel Reef (ab)
	Rennel Reef (bc)	Aureed Reef (abc)
	Warrior Reef (bc)	Campbell Reef (abc)
	Aureed Reef (bcd)	Dungeness Reef (bc)
	Bramble Reef (cde)	Bramble Reef (bc)
	Little Mary Reef (def)	Warrior Reef (bcd)
	Poll Reef (ef)	Poll Reef (cd)
	Dungeness Reef (fg)	Underdown Reef (d)
	Underdown Reef (g)	Little Mary Reef (d)
	Tom Son's Bank (g)	Tom Son's Bank (d)
	Hibernia Passage (h)	Hibernia Passage (e)
Nickel	Tom Son's Bank (a)	Poll Reef (a)
	Hibernia Passage (a)	Hibernia Passage (ab)
	Poll Reef (ab)	Tom Son's Bank (ab)
	Little Mary Reef (b)	Little Mary Reef (bc)
	Aureed Reef (c)	Aureed Reef (cd)
	Underdown Reef (c)	Underdown Reef (de)
	Dungeness Reef (c)	Rennel Reef (de)
	Rennel Reef (c)	Campbell Reef (de)
	Campbell Reef (cd)	Dungeness Reef (ef)
	Bramble Reef (de)	Warrior Reef (fg)
	Warrior Reef (ef)	Bramble Reef (gh)
	Kokope Reef (f)	Kokope Reef (h)

Metal	Pre-Monsoon	Monsoon
Lead	Kokope Reef (a)	Bramble Reef (a)
	Bramble Reef (a)	Kokope Reef (ab)
	Warrior Reef (b)	Aureed Reef (bc)
	Rennel Reef (b)	Rennel Reef (bc)
	Aureed Reef (b)	Poll Reef (bc)
	Campbell Reef (b)	Underdown Reef (cd)
	Tom Son's Bank (bc)	Dungeness Reef (cd)
	Poll Reef (bcd)	Campbell Reef (cd)
	Little Mary Reef (cd)	Tom Son's Bank (cd)
	Underdown Reef (cd)	Warrior Reef (d)
	Hibernia Passage (d)	Little Mary Reef (d)
	Dungeness Reef (d)	Hibernia Passage (e)
Selenium	Little Mary Reef (a)	Aureed Reef (a)
	Hibernia Passage (a)	Poll Reef (ab)
	Aureed Reef (ab)	Rennel Reef (bc)
	Tom Son's Bank (ab)	Dungeness Reef (cd)
	Campbell Reef (abc)	Little Mary Reef (de)
	Rennel Reef (bc)	Underdown Reef (e)
	Underdown Reef (cd)	Tom Son's Bank (e)
	Kokope Reef (cd)	Campbell Reef (e)
	Poll Reef (cd)	Kokope Reef (e)
	Warrior Reef (cd)	Hibernia Passage (e)
	Bramble Reef (d)	Warrior Reef (e)
	Dungeness Reef (d)	Bramble Reef (e)
Strontium	Warrior Reef (a)	Warrior Reef (a)
	Campbell Reef (a)	Poll Reef (ab)
	Hibernia Passage (a)	Underdown Reef (abc)
	Bramble Reef (a)	Aureed Reef (abc)
	Aureed Reef (a)	Kokope Reef (abc)
	Little Mary Reef (a)	Hibernia Passage (abc)
	Tom Son's Bank (a)	Bramble Reef (abc)
	Underdown Reef (ab)	Campbell Reef (bc)
	Rennel Reef (ab)	Tom Son's Bank (bc)
	Kokope Reef (ab)	Little Mary Reef (bc)
	Poll Reef (ab)	Rennel Reef (cd)
	Dungeness Reef (b)	Dungeness Reef (d)
Uranium	Little Mary Reef (a)	Aureed Reef (a)
	Dungeness Reef (ab)	Little Mary Reef (a)
	Hibernia Passage (bc)	Rennel Reef (ab)
	Aureed Reef (bc)	Hibernia Passage (abc)
	Bramble Reef (bc)	Tom Son's Bank (abc)
	Kokope Reef (bc)	Dungeness Reef (abc)
	Rennel Reef (bc)	Campbell Reef (abcd)
	Poll Reef (bc)	Bramble Reef (abcd)
	Tom Son's Bank (bc)	Poll Reef (abcd)
	Underdown Reef (c)	Underdown Reef (bcd)
	Campbell Reef (cd)	Kokope Reef (cd)
	Warrior Reef (d)	Warrior Reef (d)

Metal	Pre-Monsoon	Monsoon
Zinc	Bramble Reef (a)	Bramble Reef (a)
	Kokope Reef (b)	Kokope Reef (b)
	Warrior Reef (c)	Campbell Reef (c)
	Rennel Reef (c)	Rennel Reef (c)
	Campbell Reef (c)	Warrior Reef (c)
	Aureed Reef (d)	Aureed Reef (d)
	Underdown Reef (e)	Underdown Reef (d)
	Dungeness Reef (f)	Dungeness Reef (d)
	Little Mary Reef (g)	Little Mary Reef (e)
	Poll Reef (h)	Poll Reef (ef)
	Hibernia Passage (h)	Tom Son's Bank (f)
	Tom Son's Bank (h)	Hibernia Passage (f)

Shell length (mm) of mangrove cockles (*Polymesoda erosa*) collected for this study. N=15 for each station; SD = standard deviation. Means with the same letter are not significantly different from one another (at P=0.05, by Tukey-HSD test; see ANOVA table below)

Station	Mean	SD	Range
Sassie Is	100.86	5.369	88.9-113.4
Kussa Is	89.18c	4.065	81.3-98.9
Boigu Is	61.14a	8.044	48.7-80.0
Saibai Is	70.56b	3.425	65.0-76.6
Warukuik Ck	67.89ab	3.052	62.4-73.0
Bobo Is	62.05a	5.105	56.4-71.7
Parama Is	84.29cd	8.360	69.5-99.5
Daru Is	81.6d	9.210	63.4-95.7

Analysis of variance table comparing shell length amongst stations:

Source	df	SS	MS	F	P
Between	7	20865.601	2980.800	76.4558	<0.001
Within	112	4366.568	38.987		
Total	119	25232.169			

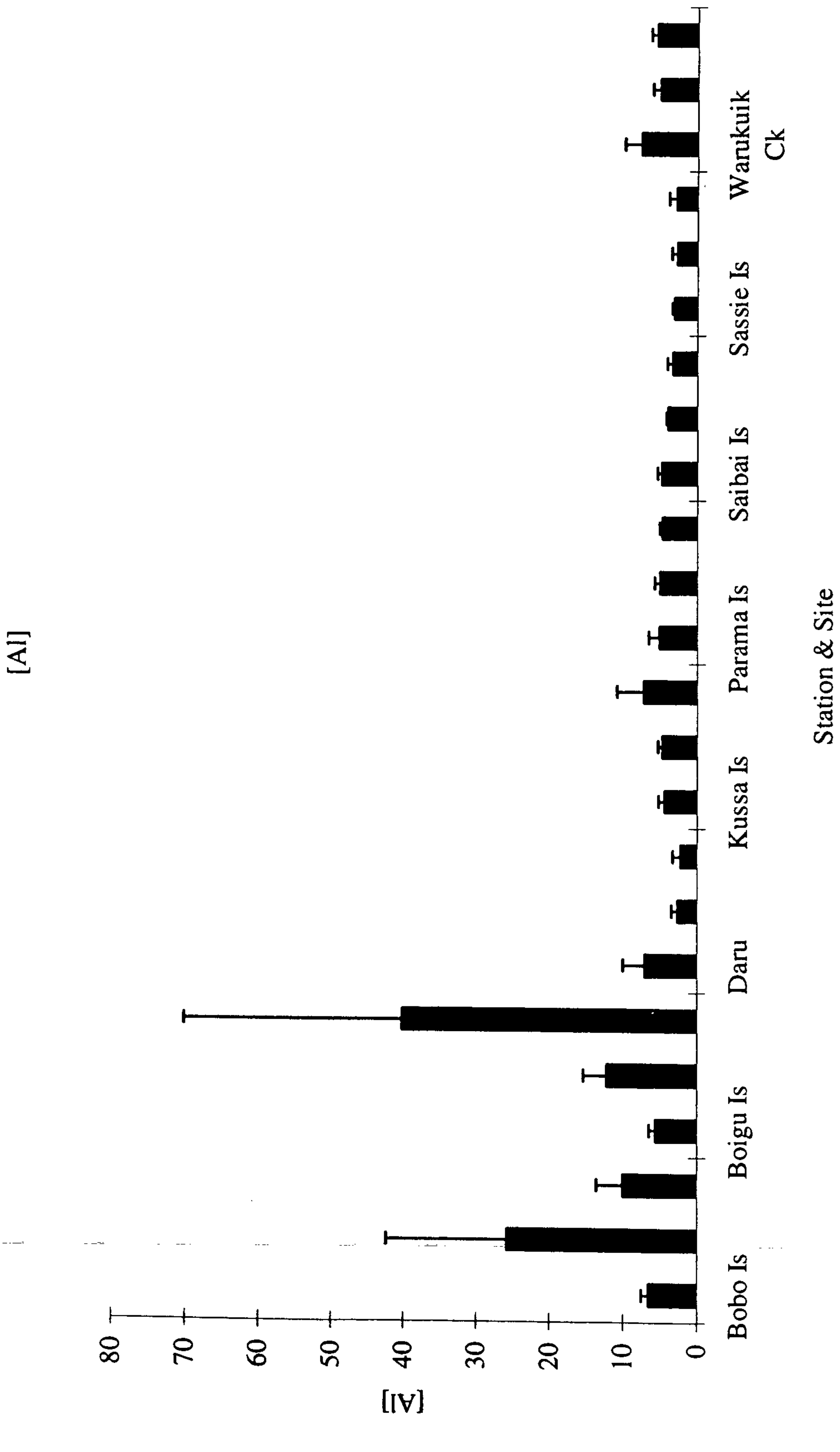
APPENDIX 13

Summary of trace metal levels (mg/kg dry weight) in whole mangrove cockle (*P. erosa*). Values shown are the mean and standard deviation (SD) for 15 specimens collected from each station (sites 1-3 pooled).

Station	Value	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sr	U	Zn
Sassie Is	Mean	0.02	2.83	9.07	0.29	0.12	0.47	2.25	55.53	0.05	0.74	0.67	2.78	1.80	45.73	0.09	81.73
	SD	0.007	1.621	1.746	0.136	0.131	0.084	0.809	20.476	0.030	0.508	0.310	0.711	0.305	11.442	0.095	29.644
Kussa Is	Mean	0.03	5.47	6.39	0.05	0.39	0.54	3.88	76.33	0.01	2.53	1.07	4.16	2.23	62.67	0.22	111.80
	SD	0.049	4.487	1.831	0.021	0.181	0.068	2.936	16.500	0.008	2.198	0.434	3.828	0.195	11.011	0.089	39.341
Boigu Is	Mean	0.04	19.30	3.03	0.14	0.55	0.85	5.37	463.27	0.16	3.77	3.79	1.48	3.62	63.07	0.70	83.87
	SD	0.038	39.267	1.361	0.102	0.532	0.390	3.379	1009.147	0.133	9.513	4.635	0.643	1.277	37.153	0.766	40.601
Saibai Is	Mean	0.02	4.01	4.63	0.08	0.24	0.48	1.93	92.73	0.10	1.59	0.76	0.44	1.65	66.87	0.10	67.00
	SD	0.011	1.339	1.421	0.044	0.101	0.065	0.404	25.166	0.033	1.161	0.280	0.142	0.196	13.233	0.037	15.090
Warukuik Ck	Mean	0.03	6.01	4.32	0.19	0.59	0.58	2.53	70.07	0.56	9.04	1.05	0.41	7.75	64.82	3.38	69.33
	SD	0.018	3.271	1.099	0.129	0.356	0.092	0.647	25.541	1.783	8.979	0.376	0.678	19.721	21.732	12.619	18.634
Bobo Is	Mean	0.04	14.11	8.33	0.21	0.20	0.77	4.09	85.47	0.19	1.00	0.93	0.28	2.25	66.40	0.67	103.07
	SD	0.025	22.099	1.916	0.316	0.080	0.266	1.833	35.191	0.282	0.357	0.223	0.084	0.283	11.025	0.249	52.933
Parama Is	Mean	0.02	4.98	3.83	0.11	0.20	1.00	2.23	50.53	0.01	4.49	1.18	0.21	1.65	48.47	0.02	78.47
	SD	0.013	2.008	1.071	0.196	0.112	0.787	0.630	10.986	0.000	3.255	0.878	0.069	0.207	7.549	0.006	17.631
Daru	Mean	0.04	4.00	3.33	0.46	0.32	0.77	2.63	62.53	0.20	8.98	0.87	0.60	2.84	36.87	0.03	65.60
	SD	0.081	4.385	2.528	1.533	0.303	0.634	2.170	25.461	0.090	7.545	0.727	0.359	2.609	10.623	0.021	25.950

APPENDIX 14 (on following pages)

Concentrations of trace metals (in mg/kg dry weight) in whole mangrove cockle collected during the pre-monsoon season in Torres Strait. Values shown are mean and standard error for each of three sites (N=5 replicates per site) in each station.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Sassie Is
Warukuik Ck
Station & Site

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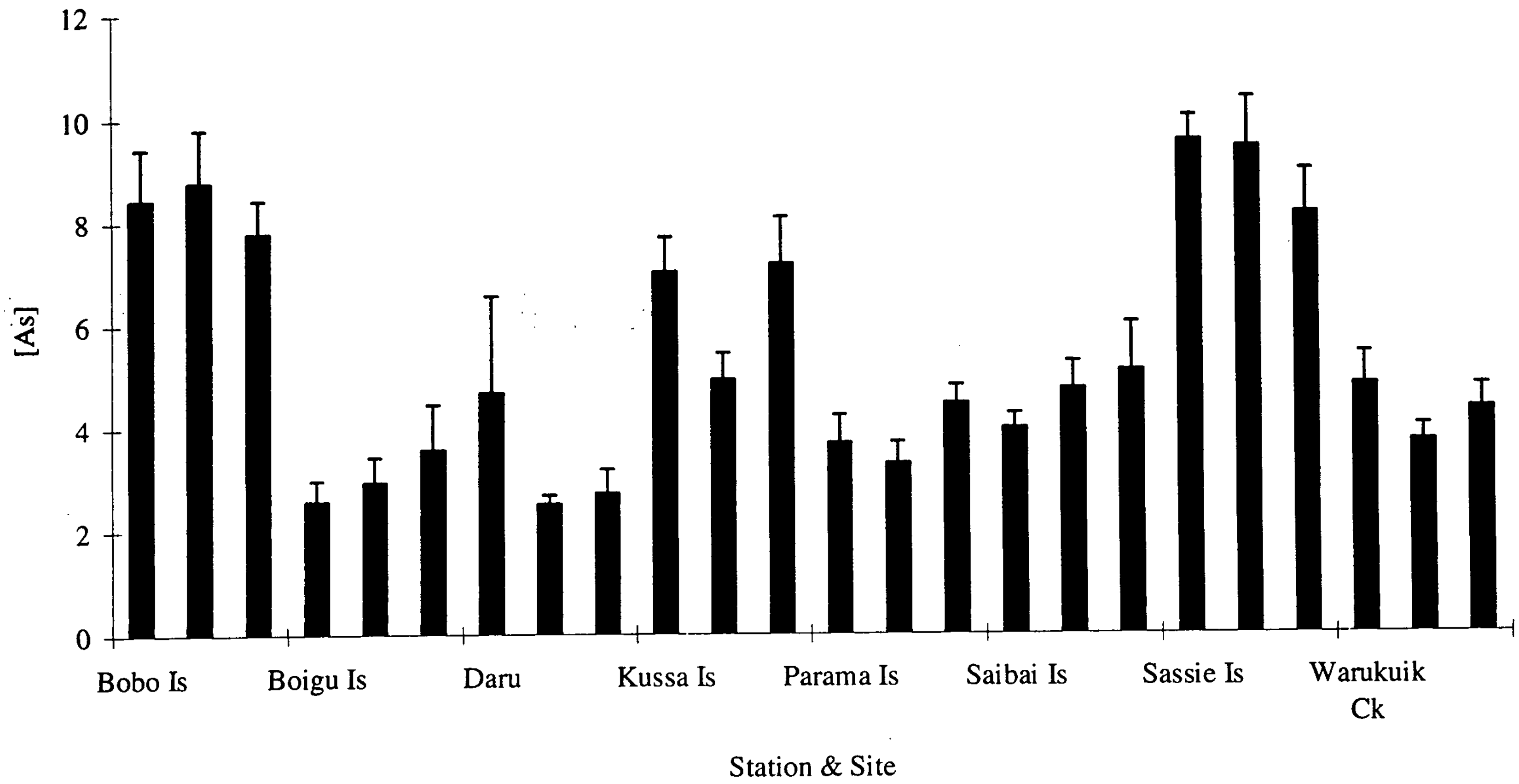
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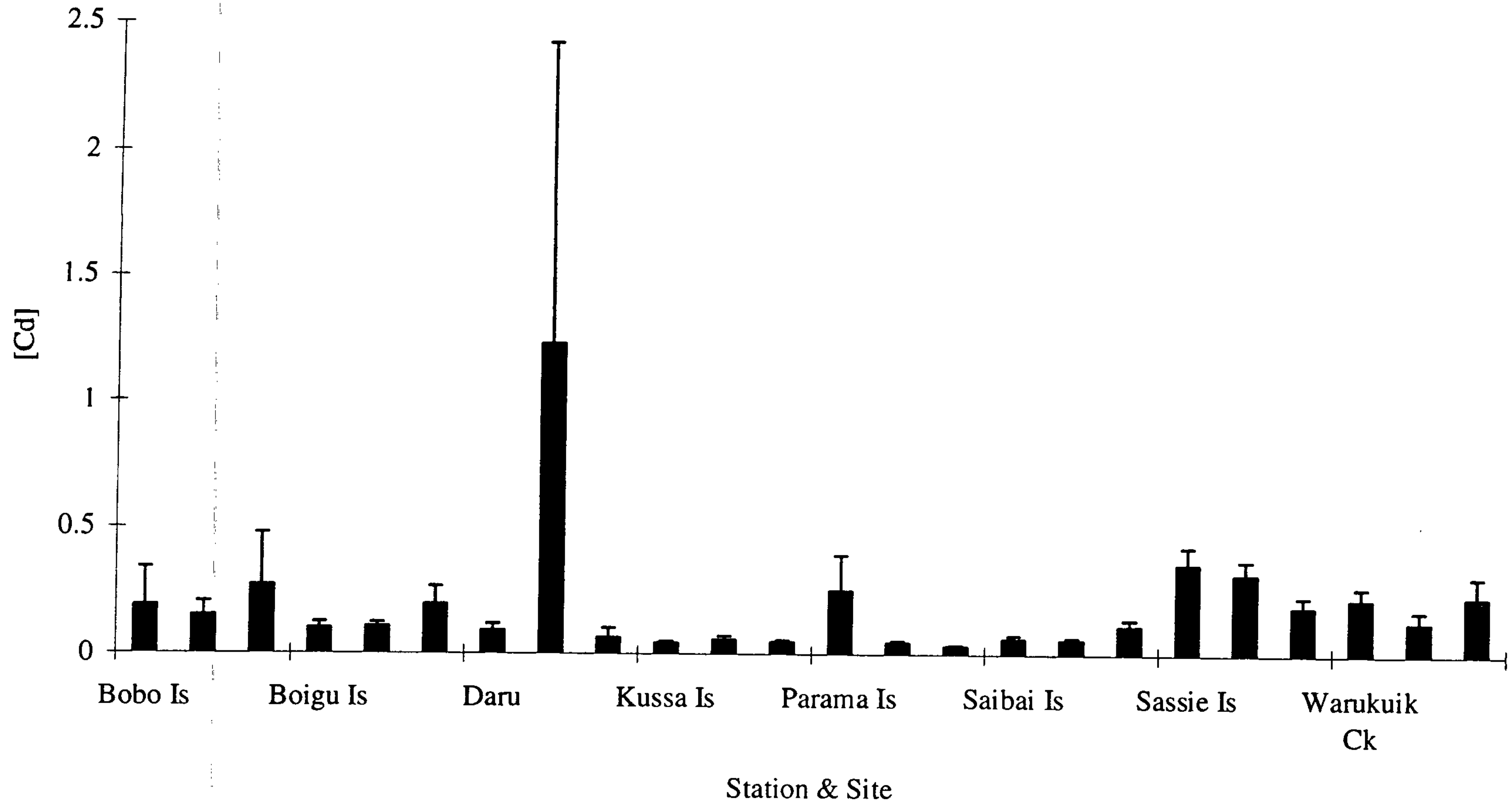
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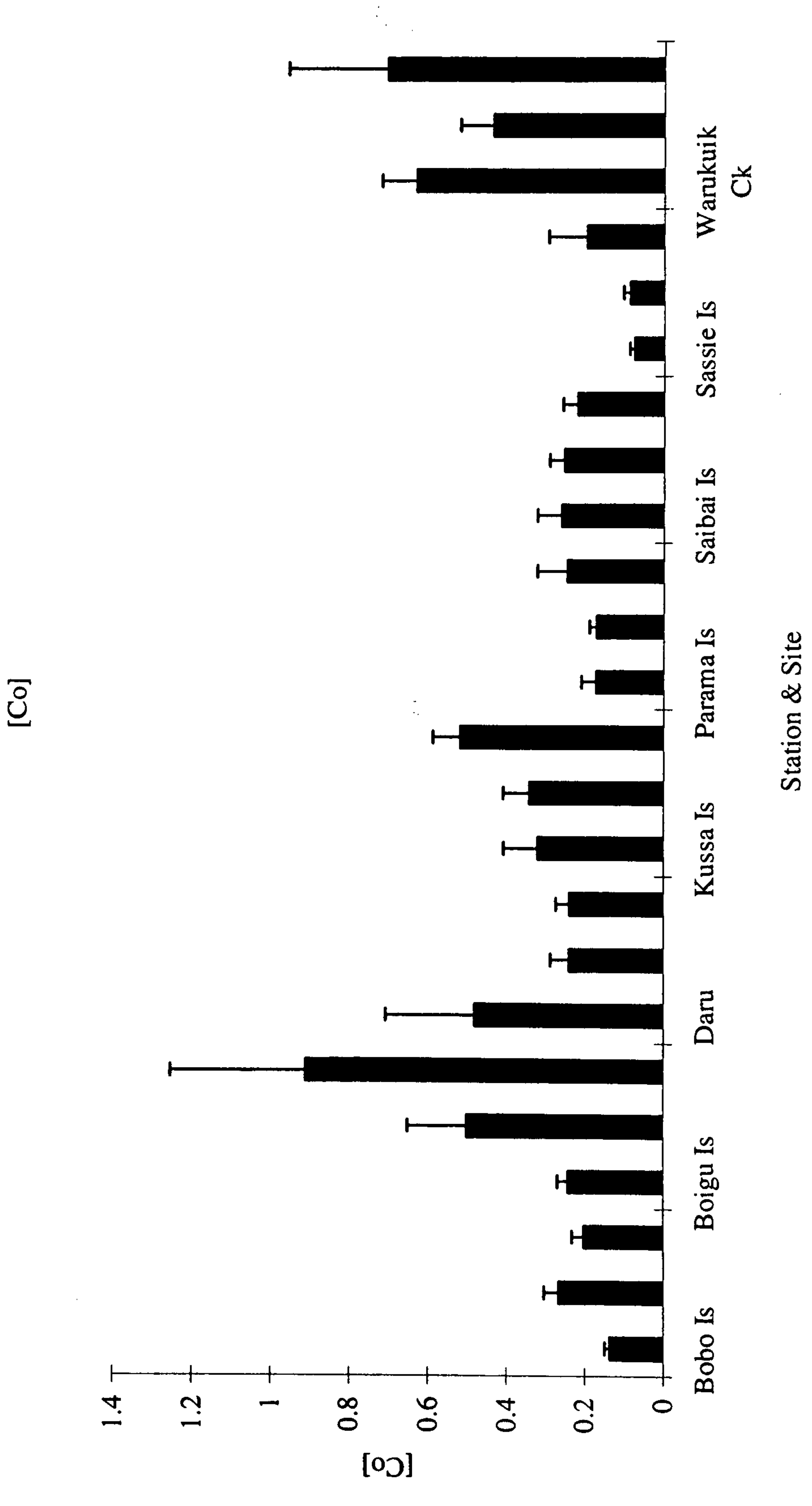
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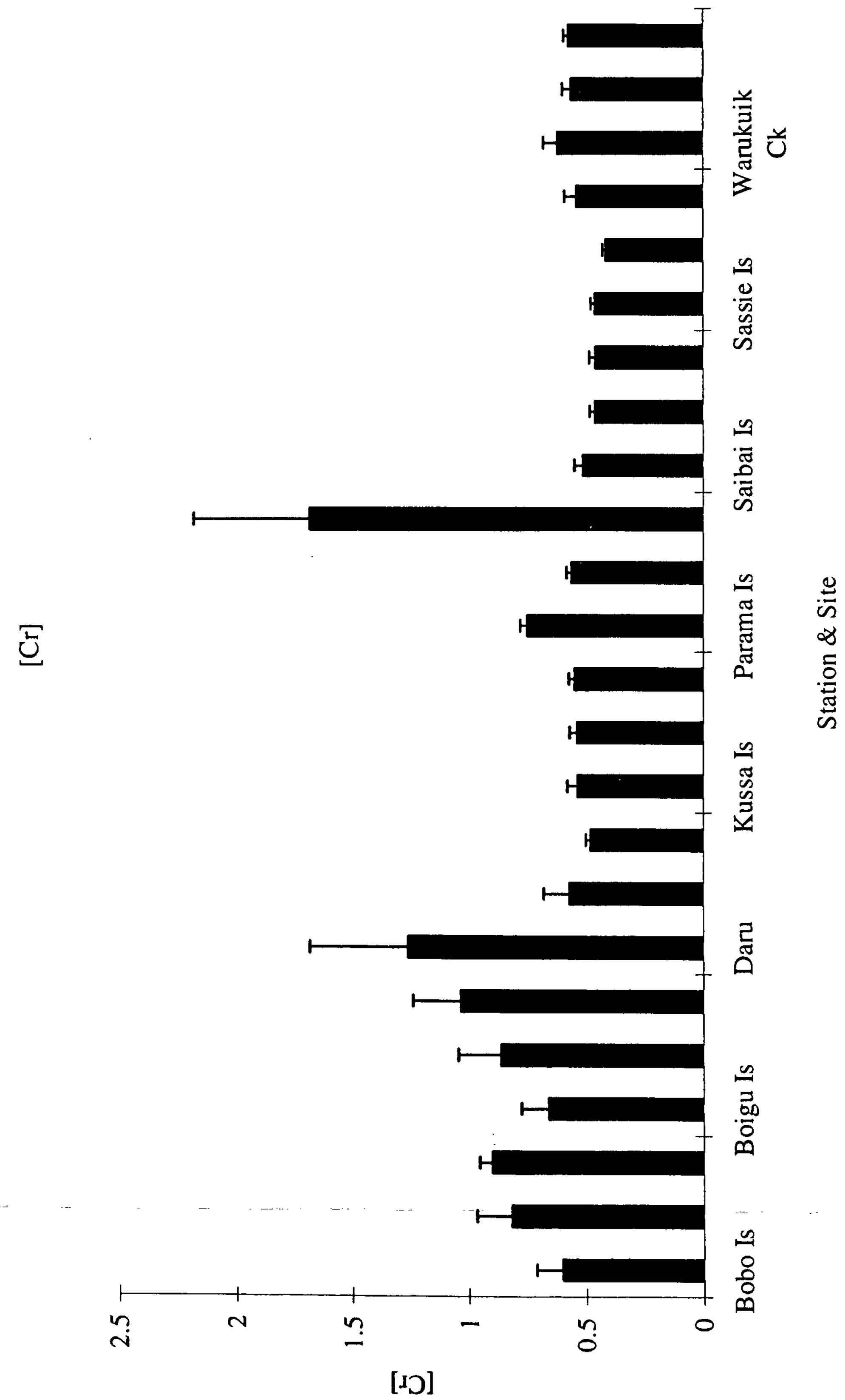
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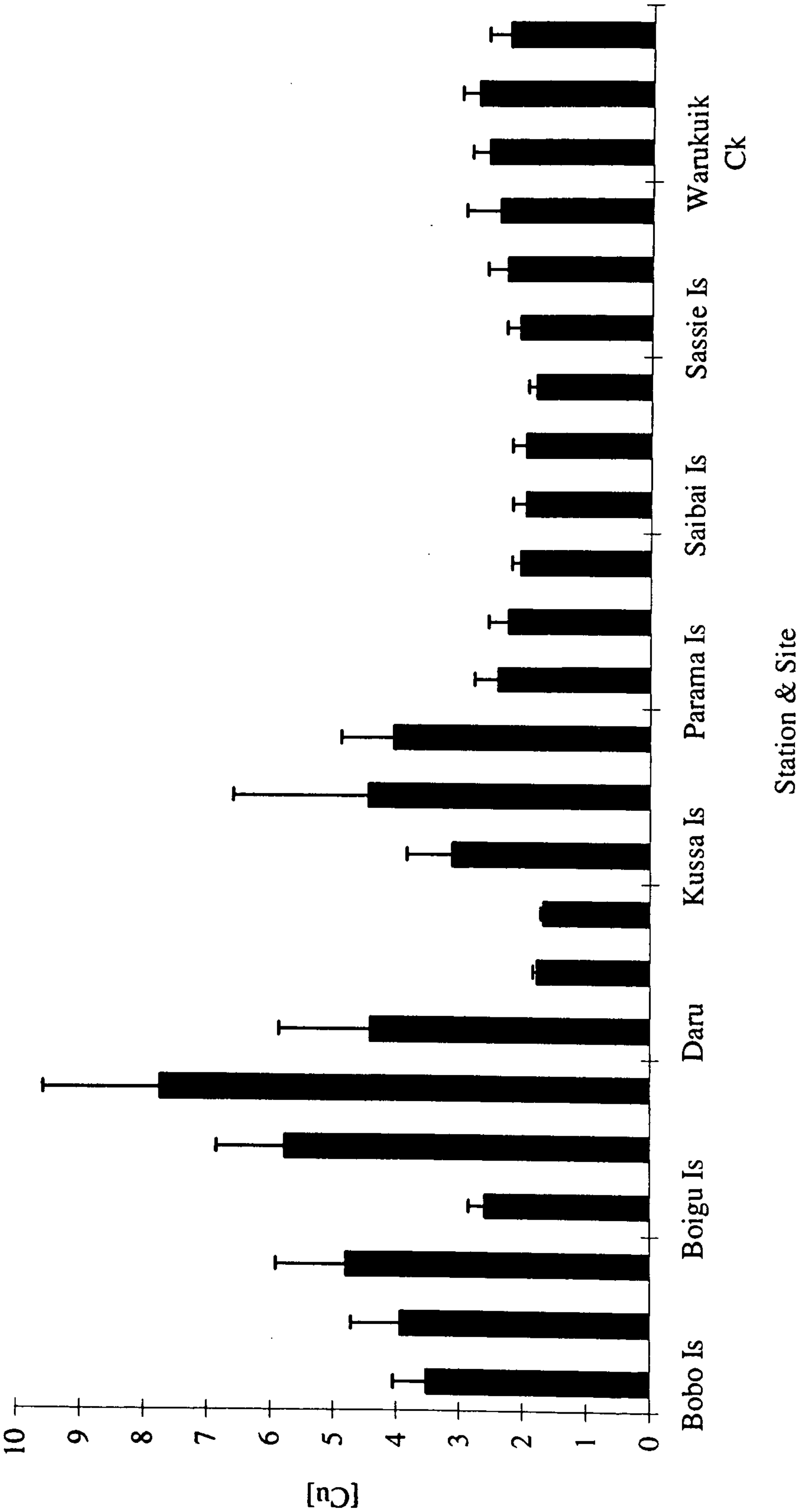
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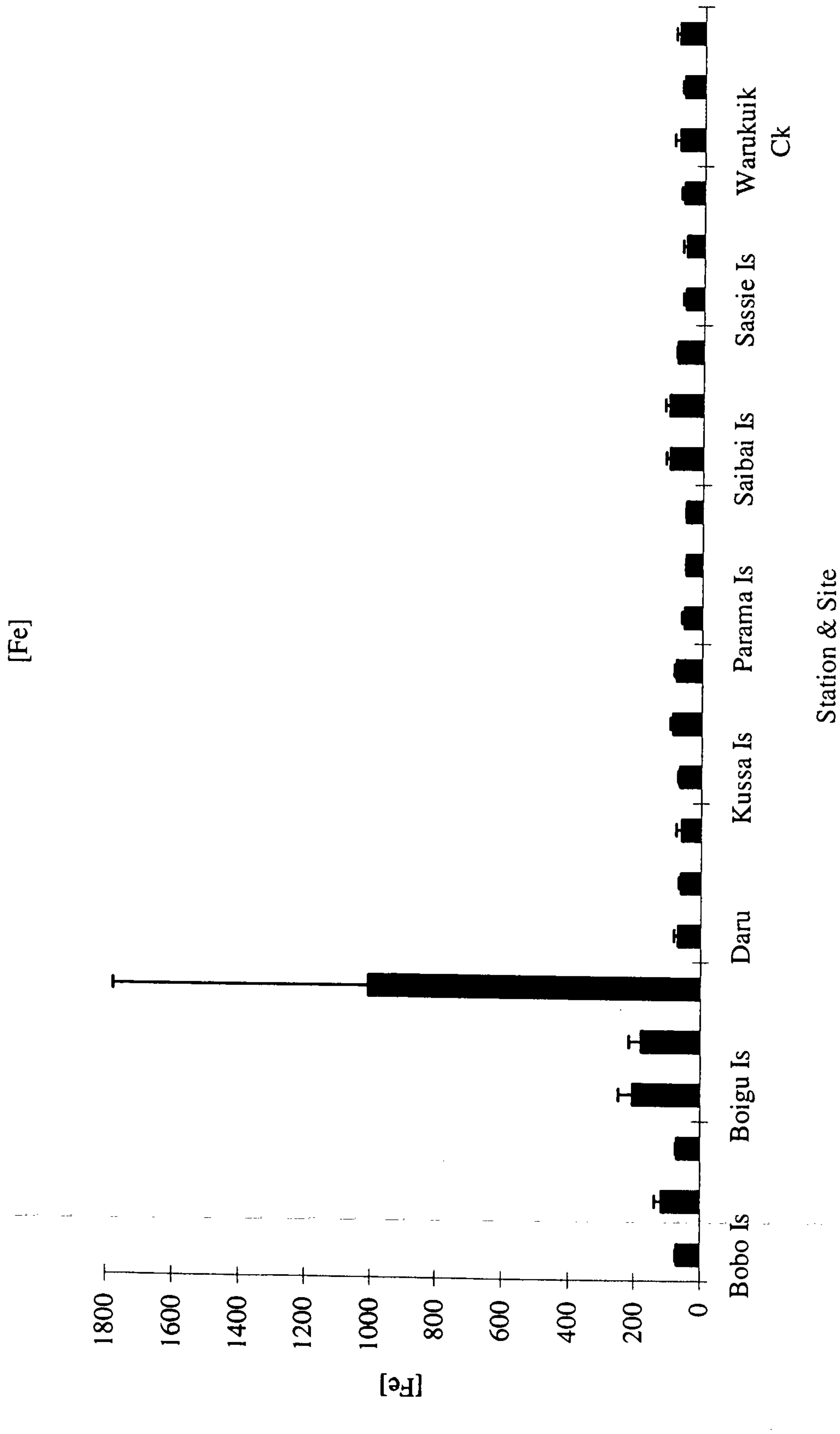
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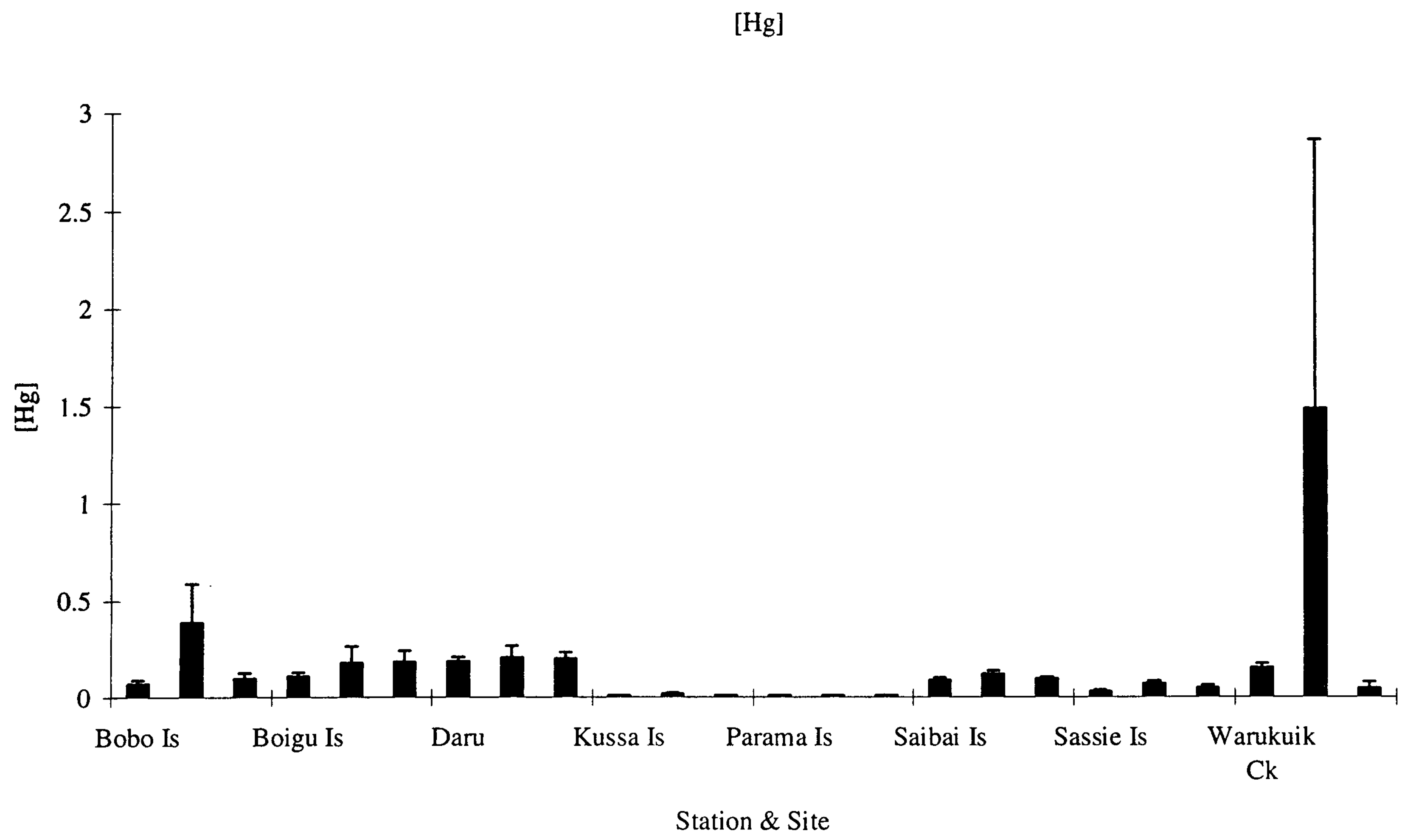
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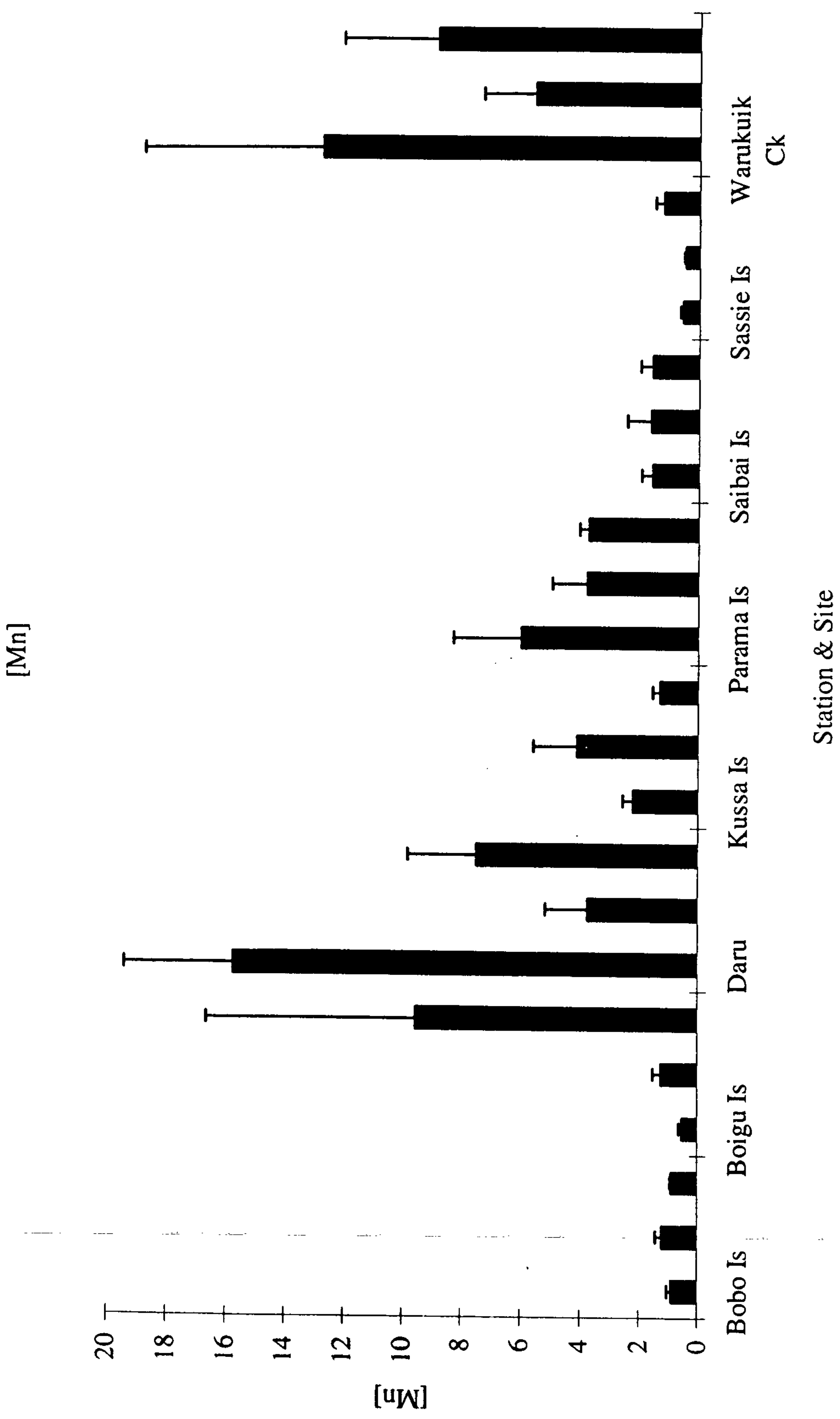
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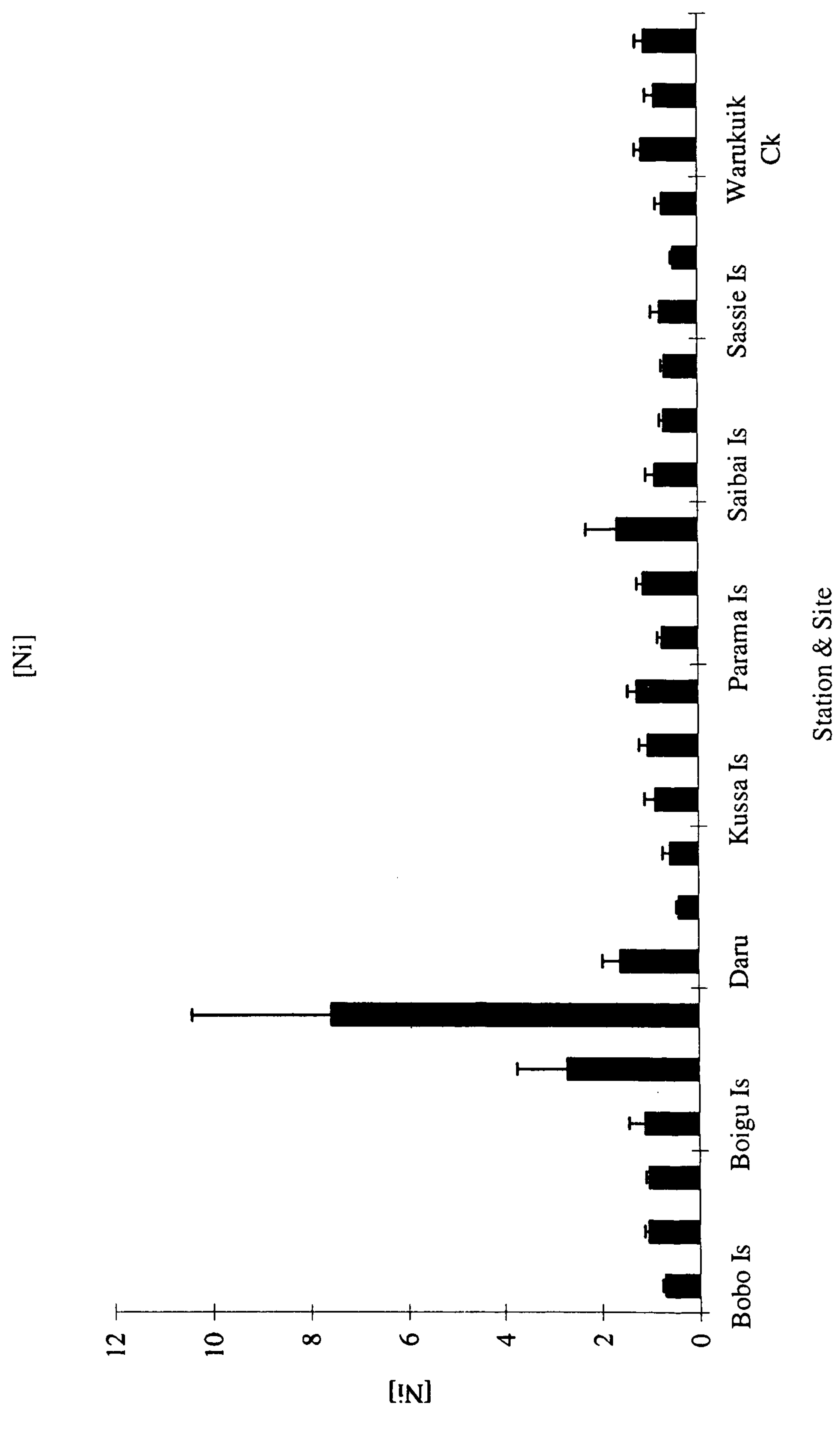
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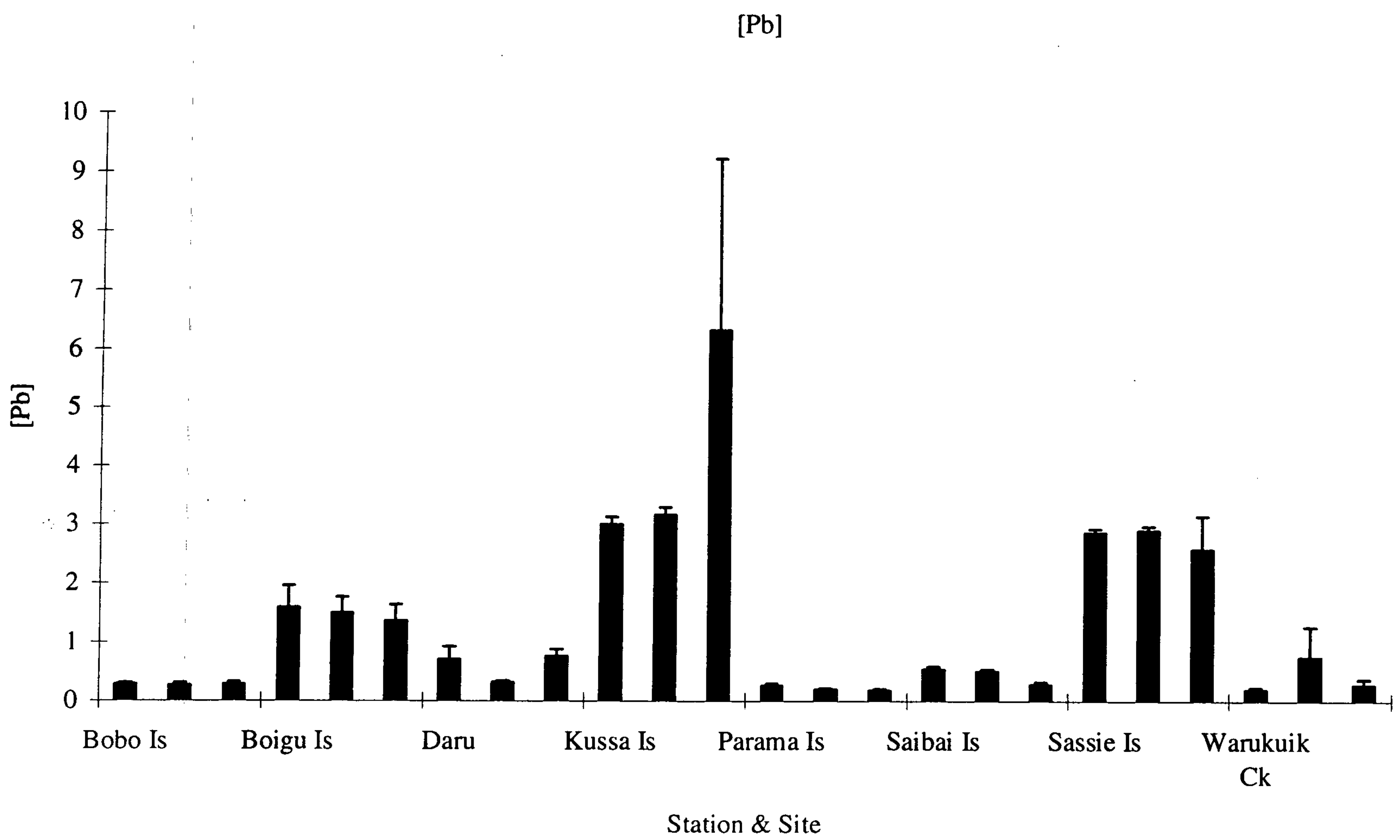
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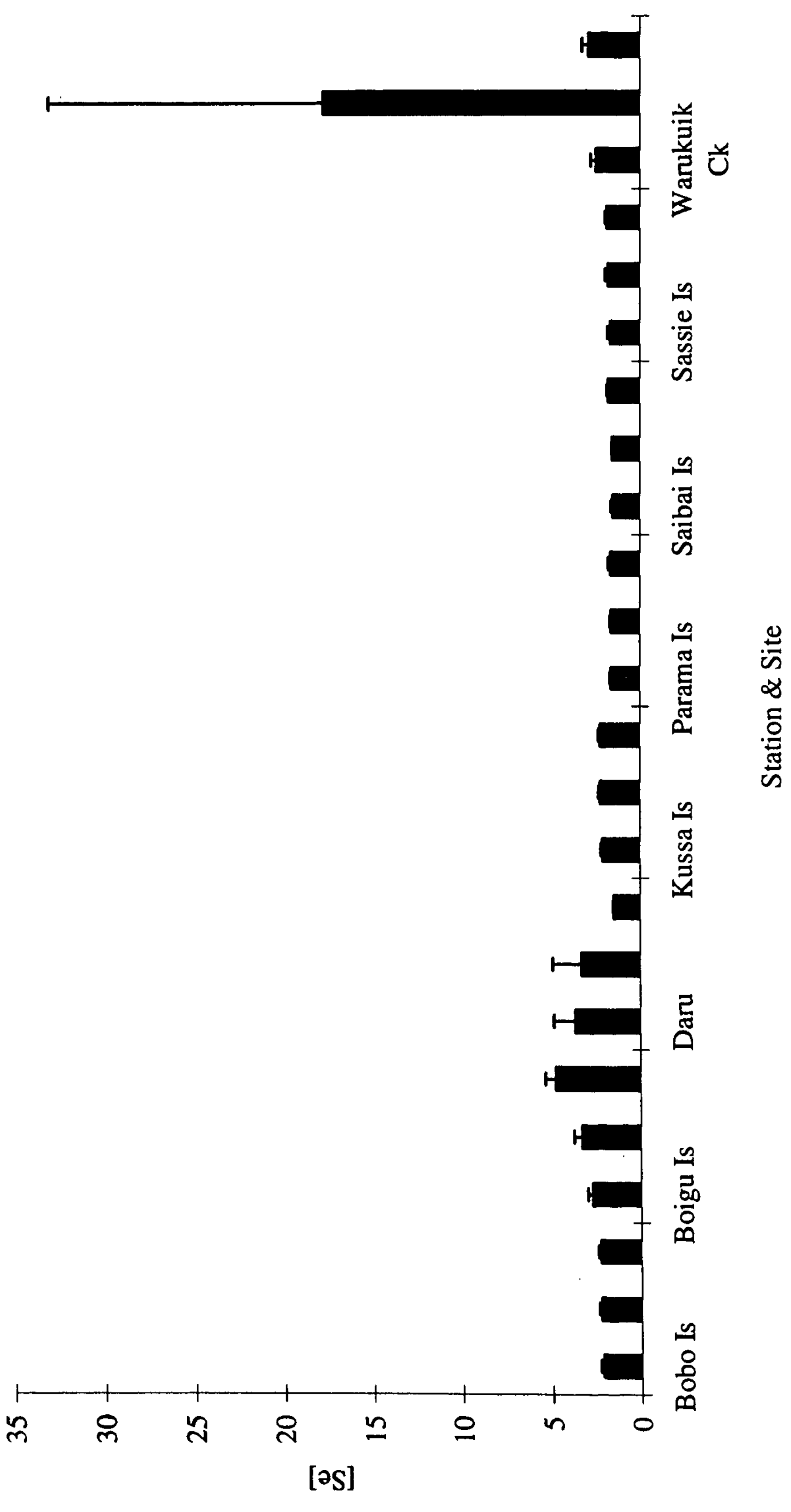

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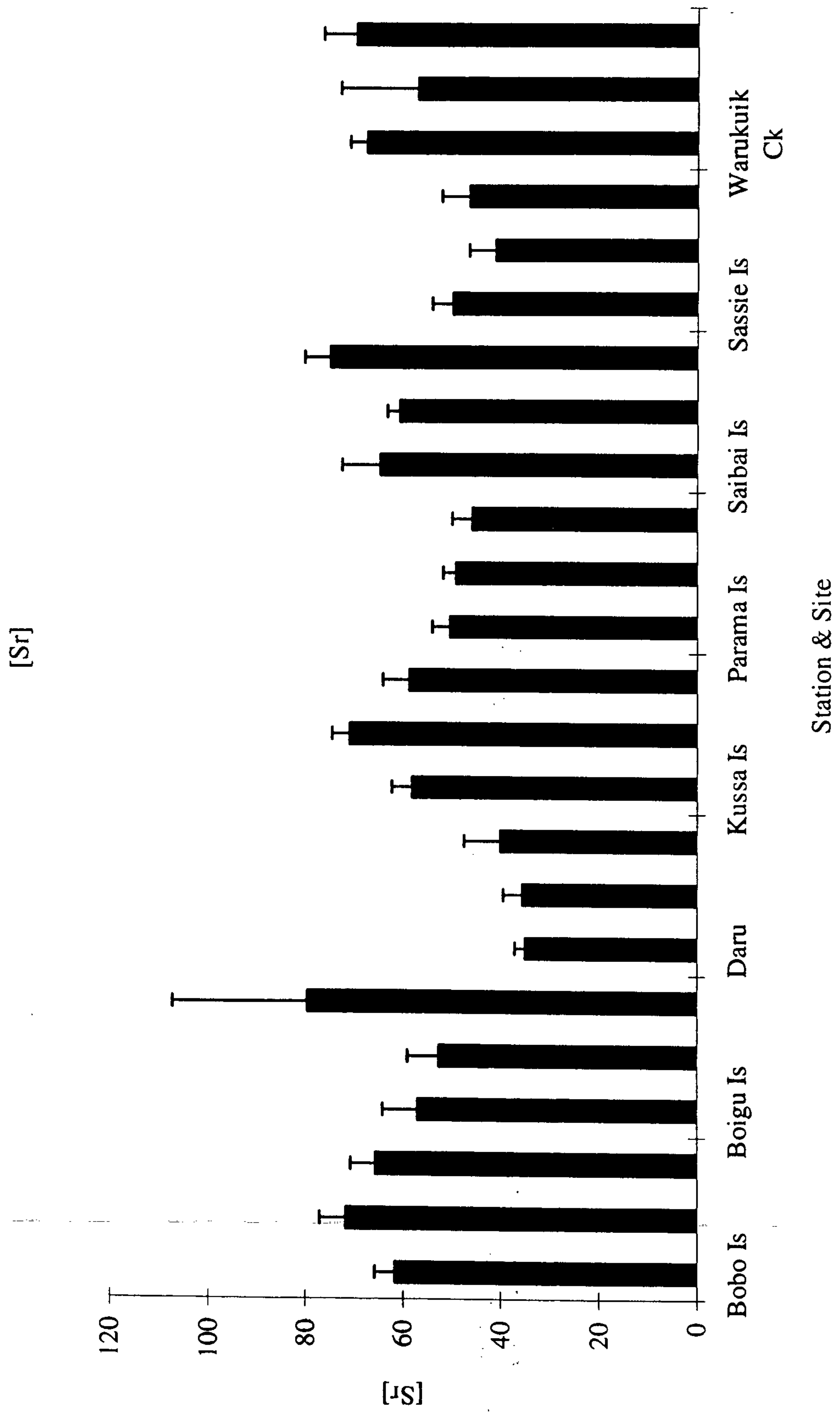
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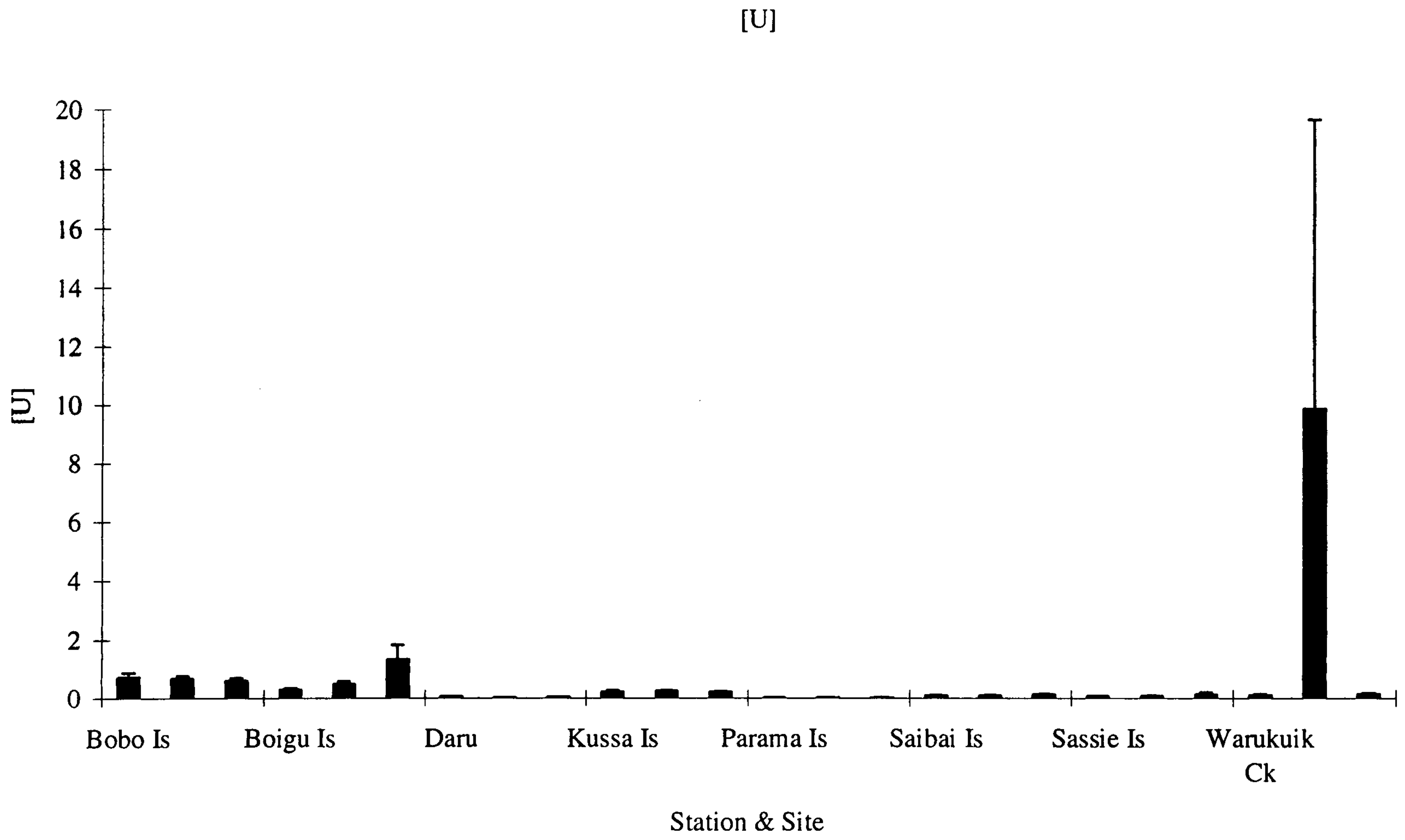
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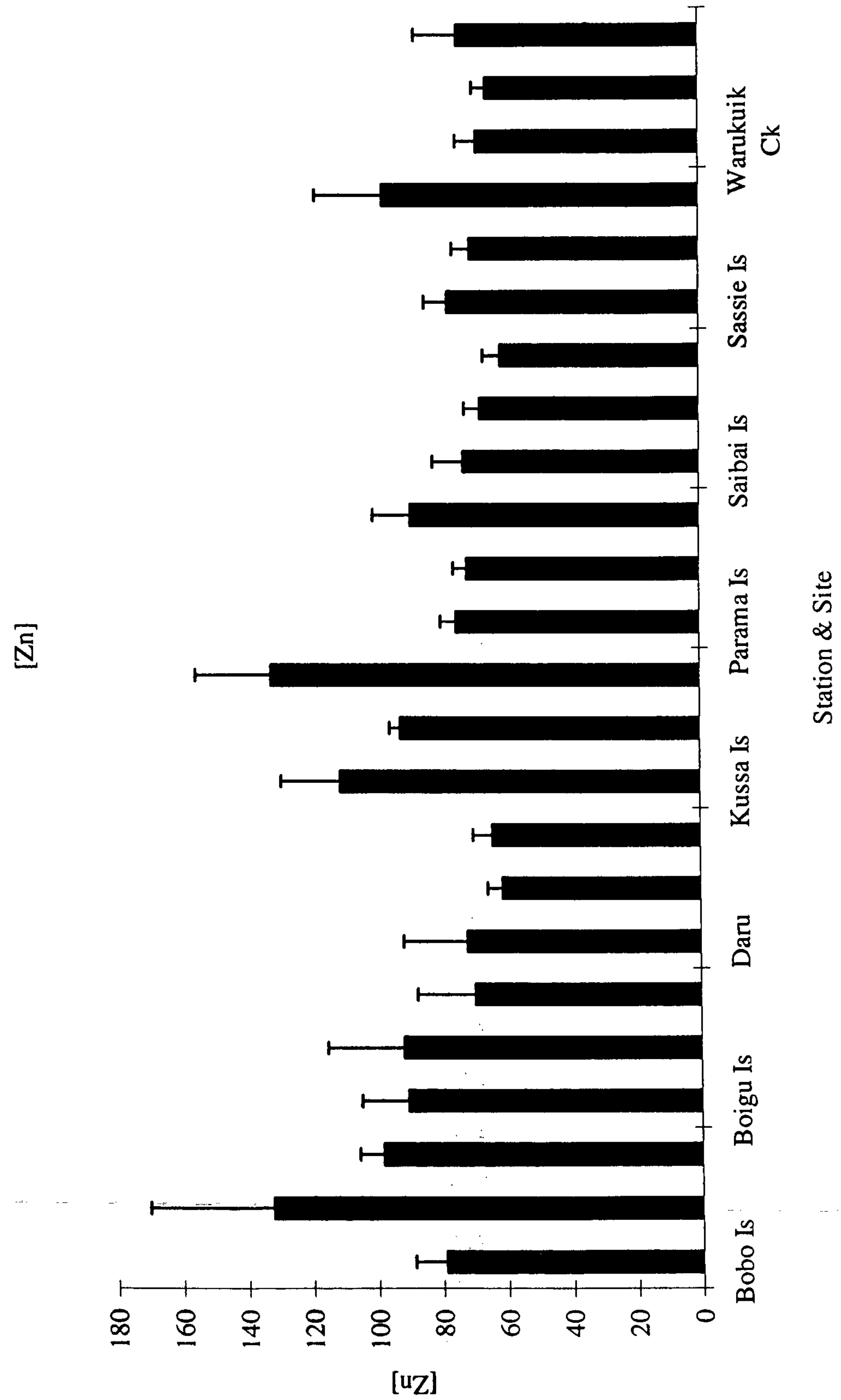
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Warukuik Ck
Station & Site

Analysis of variance (ANOVA) tables comparing the effects of station and site on trace metal levels in mangrove cockles (*P. erosa*) from the Torres Strait. Metal levels were transformed to natural logs prior to analysis. Sampling design is explained in the text. Sources of variation are significant when their p value is less than the adjusted alpha significance level of p = 0.003 (see table 2.2).

Silver

Source of variation	df	SS	MS	F	*p*
Station	7	10.050	1.436	2.52	0.06
Site(Station)	16	9.115	0.570	2.00	0.02
Residual	93	26.529	0.285		
Total	116	45.795			

Aluminium

Source of variation	df	SS	MS	F	*p*
Station	7	21.525	2.903	26.82	< 0.0001
Site(Station)	16	8.457	0.108	1.14	0.33
Residual	94	32.116	0.095		
Total	117	61.871			

Arsenic

Source of variation	df	SS	MS	F	*p*
Station	7	20.319	2.903	26.82	< 0.0001
Site(Station)	16	1.732	0.108	1.14	0.33
Residual	96	9.105	0.095		
Total	119	31.156			

Cadmium

Source of variation	df	SS	MS	F	*p*
Station	7	36.649	5.236	5.55	0.002
Site(Station)	16	15.088	0.943	1.82	0.04
Residual	95	49.095	0.517		
Total	118	100.522			

Cobalt

Source of variation	df	SS	MS	F	p
Station	7	30.137	4.305	11.41	< 0.0001
Site(Station)	16	6.039	0.377	1.47	0.13
Residual	95	24.392	0.257		
Total	118	60.294			

Chromium

Source of variation	df	SS	MS	F	p
Station	7	3.500	0.500	4.72	0.005
Site(Station)	16	1.694	0.106	1.68	0.06
Residual	91	5.719	0.063		
Total	114	10.993			

Copper

Source of variation	df	SS	MS	F	p
Station	7	10.448	1.493	4.89	0.004
Site(Station)	16	4.882	0.305	1.92	0.03
Residual	96	15.258	0.159		
Total	119	30.588			

Iron

Source of variation	df	SS	MS	F	p
Station	7	18.306	2.615	27.13	< 0.0001
Site(Station)	16	1.542	0.096	0.95	0.52
Residual	95	9.631	0.101		
Total	118	29.315			

Mercury

Source of variation	df	SS	MS	F	p
Station	7	123.338	17.620	16.45	< 0.0001
Site(Station)	16	17.137	1.071	2.77	0.001
Residual	94	36.383	0.387		
Total	117	176.415			

Manganese

Source of variation	df	SS	MS	F	p
Station	7	56.445	8.064	8.99	0.0002
Site(Station)	16	14.355	0.897	2.39	0.005
Residual	90	33.781	0.375		
Total	113	107.562			

Nickel

Source of variation	df	SS	MS	F	p
Station	7	14.430	2.061	2.59	0.05
Site(Station)	16	12.718	0.795	3.57	0.0001
Residual	95	21.150	0.223		
Total	118	47.200			

Lead

Source of variation	df	SS	MS	F	*p*
Station	7	118.833	16.976	55.11	< 0.0001
Site(Station)	16	4.929	0.308	1.22	0.27
Residual	95	24.018	0.253		
Total	118	148.333			

Selenium

Source of variation	df	SS	MS	F	*p*
Station	7	6.492	0.927	7.18	0.0006
Site(Station)	16	2.067	0.129	1.65	0.07
Residual	95	7.437	0.078		
Total	118	16.013			

Strontium

Source of variation	df	SS	MS	F	*p*
Station	7	4.794	0.685	2.49	0.06
Site(Station)	16	4.397	0.275	0.91	0.56
Residual	95	28.694	0.302		
Total	118	37.885			

Uranium

Source of variation	df	SS	MS	F	*p*
Station	7	170.593	24.370	61.93	< 0.0001
Site(Station)	16	6.296	0.393	1.34	0.19
Residual	94	27.555	0.293		
Total	117	203.171			

Zinc

Source of variation	df	SS	MS	F	*p*
Station	7	3.665	0.524	6.49	0.001
Site(Station)	16	1.291	0.081	0.83	0.65
Residual	96	9.383	0.098		
Total	119	14.340			

Trace metal levels in the kidney of *T. crocea* collected between 1978 and 1985 (reported by Denton and Heitz 1991; in ppm dry weight) and in 1992 during the present study. Stations used from the present study are closest to those used by Denton and Heitz (1991). Values for both studies are range and, in brackets, the geometric means.

Location	Date	N	Cadmium	Copper	Lead	Nickel	Zinc
Yorke Is	Nov 78	4	2.9-27.5 (12.6)	3.8-4.9 (4.5)	27.8-34.6 (31.1)	1762-4284 (3018)	6.2-8.8 (7.7)
Yorke Is	Aug 85	7	44.5-243.0 (111.0)	1.7-4.6 (3.0)	28.2-37.3 (29.9)	547.0-1566.0 (1023.0)	242.0-1389.0 (727.0)
Marakai Is	Aug 85	8	70.3-252.0 (140.0)	2.7-19.0 (4.6)	22.2-60.3 (47.7)	911.0-2922.0 (1414.0)	1.8-98.1 (5.9)
Zagai Is	June 85	4	75.7-173.0 (119.0)	4.1-6.0 (4.3)	21.5-35.2 (28.4)	256.0-1324.0 (801)	4.3-114.0 (14.3)
Dungeness Rf	Oct 92	4 0	3.9-190.0 (81.25)	1.1-9.1 (2.6)	9.1-388.0 (18.12)	600.0-2100.0 (1120.6)	3.1-86.0 (11.3)
Rennel Rf	Oct 92	4 0	29.0-200.0 (118.6)	1.5-7.5 (2.7)	15.0-45.0 (26.8)	690.0-2500.0 (1092.8)	3.0-510.0 (106.1)

Comparison between Torres Strait (this study) and comparable Great Barrier Reef locations of the levels (in ppm dry weight) of cadmium and copper in kidneys of *T. crocea*. Data for nearshore and midshelf locations for the Great Barrier Reef (GBR) are from Burdon-Jones and Denton (1984a); data for offshore GBR locations are from Burdon-Jones and Denton (1984b). Values shown are range and geometric means (in parentheses). Numbers of samples are N=10 for Orpheus and Lizard Islands; N=4 for Carter Reef; N=40 for all Torres Strait reefs except Bramble Reef in Oct 92 when N=36.

		NEARSHORE: CADMIUM		
GBR Date	**Orpheus Is**	**Torres Strait Date**	**Kokope Reef**	**Bramble Reef**
April 82	8.26-135.0 (30.50)	Oct 92	110.0-530.0 (242.03)	32.0-300.0 (145.88)
July 82	8.06-35.89 (20.66)	March 93	68.0-330.0 (210.89)	25.0-210.0 (104.25)
October 82	12.42-106.0 (43.63)			
January 83	6.02-54.06 (24.65)			
		NEARSHORE: COPPER		
GBR Date	**Orpheus Is**	**Torres Strait Date**	**Kokope Reef**	**Bramble Reef**
April 82	3.54-15.18 (5.84)	Oct 92	1.8-6.7 (3.18)	2.1-11.0 (3.9)
July 82	3.34-7.18 (4.73)	March 93	1.5-5.6 (2.61)	1.7-8.9 (3.2)
October 82	3.28-20.19 (5.40)			
January 83	2.58-5.97 (3.86)			
		MIDSHELF: CADMIUM		
GBR Date	**Lizard Is**	**Torres Strait Date**	**Rennel Rf**	**Dungeness Rf**
April 82	2.18-30.85 (6.51)	Oct 92	29.0-200.0 (118.60)	3.9-190.0 (81.25)
July 82	1.61-34.85 (7.23)	March 93	60.0-270.0 (139.38)	28.0-240.0 (109.55)
October 82	1.97-30.34 (5.72)			
January 83	1.05-59.26 (5.09)			
		MIDSHELF: COPPER		
GBR Date	**Lizard Is**	**Torres Strait Date**	**Rennel Rf**	**Dungeness Rf**
April 82	2.22-3.46 (2.77)	Oct 92	1.5-7.5 (2.74)	1.1-9.1 (2.56)
July 82	2.38-4.30 (3.11)	March 93	0.51-6.2 (2.32)	0.91-5.1 (1.84)
October 82	2.09-4.02 (2.92)			
January 83	1.98-5.54 (3.93)			

OFFSHORE: CADMIUM				
GBR Date	**Carter Reef**	**Torres Strait Date**	**Hibernia Passage**	**Little Mary Reef**
Feb 81	3.37-26.03 (15.53)	March 93	1.5-91.0 (22.76)	2.6-120.0 (36.95)

OFFSHORE: COPPER				
GBR Date	**Carter Reef**	**Torres Strait Date**	**Hibernia Passage**	**Little Mary Reef**
Feb 81	3.48-4.07 (3.83)	March 93	0.78-2.5 (1.51)	1.3-10.0 (1.93)

APPENDIX 18

Concentrations (mg/kg wet weight) of metals for which an MPC exists for fishes. The MPC values are shown in brackets next to the metals. n = sample size; SD = standard deviation; bdl = below detection limit

Species	Sample	Tissue	n	Value	Total As	Inorg As (1.0)	Cd (0.2)	Cu (10.0)	Hg (0.5)	Pb (1.5)	Se (1.0)	Zn (150.0)
S. commersonianus	Fresh gutted	Muscle	1		1.2	0.0156	bdl	0.56	0.07	0.04	0.52	6.9
S. commerson	Fresh gutted	Muscle	1		0.64	0.0083	bdl	0.19	0.26	0.08	0.38	6.2
C. ignoblis	Fresh gutted	Muscle	1		1.8	0.0234	bdl	0.34	0.04	0.04	0.34	5.5
M. georgi	Fresh gutted	Muscle	1		0.66	0.0086	bdl	0.18	bdl	0.02	0.12	3.2
	Grilled ungutted	Muscle	1		2.9	0.0377	bdl	0.24	bdl	0.09	0.38	6.2
C. cyanodus	Fresh gutted	Muscle	1		11	0.143	bdl	0.1	0.06	bdl	0.23	7.9
	Grilled ungutted	Muscle	1		7.6	0.0988	0.02	0.15	0.1	0.03	0.46	9.6
L. carponotatus	Fresh gutted	Muscle	1		3.9	0.0507	bdl	1.6	0.08	0.05	0.24	6.8
	Grilled ungutted	Muscle	1		2.7	0.0351	bdl	0.16	0.14	0.04	0.46	7.5
L. laticaudis	Grilled ungutted	Muscle	1		8.4	0.1092	bdl	0.12	0.06	0.06	0.4	5.4
H. ovalis	Fresh ungutted	Whole	15	Mean	1.23	0.016	0.015	0.35	bdl	0.013	0.34	2.58
				SD	0.430	0.0056	0.021	0.124		0.005	0.117	0.832
				Range	0.75-2.3	0.0098-0.0299	0.01-0.09	0.16-0.64		0.01-0.02	0.14-0.52	1.50-3.00
M. cephalus	Grilled ungutted	Muscle	1		0.76	0.0099	bdl	0.42	bdl	0.1	0.48	7.1
L. calcarifer	Grilled ungutted	Muscle	1		0.51	0.0066	bdl	0.23	1.7	0.04	0.37	3.9
S. dimidiatus	Fresh gutted	Muscle	1		2.7	0.0351	12.0	120.0	0.08	0.83	0.37	34.0

Species	Sample	Tissue	n	Value	Total As	Inorg As (1.0)	Cd (0.2)	Cu (10.0)	Hg (0.5)	Pb (1.5)	Se (1.0)	Zn (150.0)
G. speciosus	Fresh gutted	Muscle	2	Mean	2.25	0.0293	bdl	0.53	0.07	0.045	0.395	8.3
				SD	0.212	0.0028		0.269	0.014	0.021	0.021	1.838
				Range	2.1-2.4	0.0273-0.0312		0.34-0.72	0.06-0.08	0.03-0.06	0.38-0.41	7.0-9.6
A. caudovittatus	Fresh gutted	Muscle	5	Mean	1.08	0.014	bdl	0.52	0.05	0.09	0.35	14.2
				SD	0.266	0.0035		0.172	0.012	0.049	0.054	4.025
				Range	0.68-1.2	0.0088-0.0156		0.33-0.72	0.03-0.06	0.03-0.16	0.29-0.44	12.0-19.0
H. far	Fresh gutted	Muscle	5	Mean	1.28	0.0166	bdl	0.30	bdl	0.044	0.58	13.92
				SD	0.647	0.0084		0.033		0.005	0.216	5.791
				Range	0.64-2.1	0.0083-0.0273		0.24-0.32		0.04-0.05	0.43-0.96	8.6-22.0
V. seheli	Grilled ungutted	Muscle	2	Mean	0.71	0.0092	bdl	0.41	0.02	0.035	0.285	4.3
				SD	0.183	0.0024		0.162	0	0.007	0.120	0.707
				Range	0.58-0.84	0.0075-0.0109		0.29-0.52	0.02	0.03-0.04	0.2-0.37	3.8-4.8
	Grilled ungutted	Gut	2	Mean	1.65	0.0215	0.035	1.75	bdl	0.05	1.3	78.5
				SD	0.495	0.0064	0.021	0.636		0.014	0.424	24.749
				Range	1.3-2.0	0.0169-0.0260	0.02-0.05	1.3-2.2		0.04-0.06	1.0-1.6	61.0-96.0

APPENDIX 19. Concentrations (mg/kg wet weight) of metals for which an MPC exists for the mangrove cockle (*Polymesoda erosa*). The MPC values are shown in brackets next to the metals. n = sample size; SD = standard deviation; bdl = below detection limit

Station	Tissue	n	Value	Total As	Inorg As (1.0)	Cd (0.2)	Cu (10.0)	Hg (0.5)	Pb (1.5)	Se(1.0)	Zn (150.0)
Sassie Is	Whole	15	Mean	1.89	0.0246	0.06	0.46	0.012	0.57	0.35	16.53
			SD	0.45	0.0059	0.027	0.137	0.006	0.157	0.116	4.642
			Range	1.1-2.6	0.0143-0.0338	0.01-0.11	0.30-0.77	0.01-0.03	0.08-0.77	0.01-0.52	13.0-31.0
Kusar Is	Whole	15	Mean	1.11	0.0144	0.011	0.66	bdl	0.72	0.38	19.07
			SD	0.396	0.0051	0.0028	0.504		0.694	0.052	7.363
			Range	0.46-1.8	0.006-0.0234	0.01-0.02	0.3-2.2		0.21-3.0	0.26-0.46	11.0-37.0
Boigu Is	Whole	15	Mean	0.50	0.0065	0.02	0.86	0.03	0.22	0.57	14.04
			SD	0.209	0.0027	0.015	0.592	0.021	0.101	0.257	6.454
			Range	0.29-0.72	0.0038-0.0094	0.01-0.07	0.01-2.2	0.01-0.09	0.01-0.34	0.01-0.86	7.4-30.0
Saibai Is	Whole	15	Mean	0.83	0.0108	0.012	0.34	0.019	0.08	0.29	11.94
			SD	0.278	0.0036	0.006	0.082	0.006	0.028	0.036	2.624
			Range	0.46-0.94	0.006-0.0122	0.01-0.03	0.25-0.59	0.01-0.03	0.04-0.13	0.23-0.35	8.2-16.0
Warukuik Ck	Whole	15	Mean	0.73	0.0095	0.03	0.43	0.07	0.06	1.03	11.79
			SD	0.238	0.0031	0.018	0.140	0.202	0.076	2.235	3.620
			Range	0.33-1.1	0.0043-0.0143	0.01-0.08	0.21-0.65	0.01-0.8	0.01-0.1	0.28-9.1	7.3-18.0
Bobo Is	Whole	15	Mean	0.97	0.0126	0.03	0.49	0.02	0.03	0.26	12.07
			SD	0.221	0.0029	0.042	0.283	0.027	0.01	0.037	5.592
			Range	0.66-1.5	0.0086-0.0195	0.01-0.17	0.23-1.4	0.01-0.11	0.02-0.06	0.2-0.31	4.7-29.0
Parama Is	Whole	15	Mean	0.70	0.0091	0.02	0.42	bdl	0.04	0.30	14.53
			SD	0.174	0.0023	0.033	0.147		0.017	0.028	2.10
			Range	0.44-1.0	0.0057-0.013	0.01-0.14	0.31-0.78		0.02-0.08	0.26-0.36	12.0-20.0
Daru	Whole	15	Mean	0.71	0.0092	0.11	0.55	0.04	0.12	0.60	14.09
			SD	0.574	0.0075	0.357	0.453	0.018	0.077	0.544	6.58
			Range	0.28-2.7	0.0036-0.0351	0.01-1.4	0.27-1.7	0.02-0.09	0.05-0.34	0.25-2.0	6.7-33.0

APPENDIX 20

Concentrations (mg/kg wet weight) of metals, for which an MPC exists, in crustaceans. The MPC values are shown in brackets next to the metals. n = sample size; SD = standard deviation; bdl = below detection limit.

Species	Sample	Tissue	n	Value	Total As	Inorg As (1.0)	Cd (0.2)	Cu (10.0)	Hg (0.5)	Pb (1.5)	Se(1.0)	Zn (150.0)
Mud crab (*S. serrata*)	Boiled	Body muscle	5	Mean	2.08	0.027	0.02	7.66	0.02	0.02	0.68	30.2
				SD	0.618	0.008	0.009	2.645	0.007	0.005	0.431	4.604
				Range	1.3-2.7	0.0169-0.0351	0.01-0.03	4.6-11.0	0.01-0.03	0.02-0.03	0.11-1.2	26.0-36.0
Crayfish (*P. ornatus*)	Fresh	Tail muscle	8	Mean	34.12	0.444	bdl	5.7	0.04	0.06	0.55	24.37
				SD	14.317	0.186		1.386	0.012	0.015	0.069	2.669
				Range	23.0-64.0	0.299-0.83		3.9-6.8	0.02-0.06	0.04-0.09	0.45-0.68	20.0-28.0
	Fresh	Head	2	Mean	8.0	0.104	1.06	5.80	bdl	0.02	0.41	11.7
				SD	7.07	0.092	1.471	3.959		0.014	0.269	13.152
				Range	3.0-13.0	0.039-0.17	0.02-2.1	3.0-8.6		0.01-0.03	0.22-0.60	2.4-21.0
	Boiled	Head	3	Mean	18.33	0.238	1.37	50.33	0.04	0.056	1.03	58.0
				SD	9.504	0.124	1.068	26.274	0.017	0.006	0.415	25.0
				Range	9.0-28.0	0.12-0.36	0.74-2.6	30.0-80.0	0.02-0.05	0.05-0.06	0.58-1.4	33.0-83.0

APPENDIX 21

Concentrations (mg/kg wet weight) of metals, for which an MPC exists, in tissues of dugong (*Dugong dugon*). The MPC values are shown in brackets next to the metals. n = sample size; SD = standard deviation; bdl = below detection limit.

Tissue	n	Value	Total As	Inorg As (1.0)	Cd (0.2)	Cu (10.0)	Hg (0.5)	Pb (1.5)	Se(1.0)	Zn (150.0)
Muscle+fat	2	Mean	3.13	0.041	0.02	3.37	bdl	0.025	0.29	5.2
		SD	4.334	0.056	0.014	4.426		0.007	0.099	3.25
		Range	0.07-6.2	0.0009-0.081	0.01-0.03	0.24-6.5		0.02-0.03	0.22-0.36	2.9-7.5
Muscle	2	Mean	0.04	0.0005	0.015	0.205	bdl	0.035	0.105	12.6
		SD	0.014	0.0002	0.007	0.106		0.007	0.064	16.122
		Range	0.03-0.05	0.0004-0.0007	0.01-0.02	0.13-0.28		0.03-0.04	0.06-0.15	1.2-24.0
Liver	3	Mean	0.27	0.004	6.43	184.0	0.03	0.08	1.37	470.0
		SD	0.115	0.0015	2.743	175.237	0.01	0.029	0.252	326.956
		Range	0.18-0.40	0.0023-0.0052	4.8-9.6	22.0-370.0	0.02-0.04	0.05-0.10	1.1-1.6	100.0-720.0
Kidney	3	Mean	0.25	0.0033	8.17	2.67	0.02	0.06	3.40	31.0
		SD	0.085	0.0011	7.721	1.514	0.017	0.015	3.897	21.377
		Range	0.19-0.35	0.0025-0.0046	2.7-17.0	1.6-4.4	0.01-0.04	0.04-0.07	1.1-7.9	14.0-55.0
Intestine	1		0.08	0.001	0.09	.44	bdl	0.03	0.11	30.0

APPENDIX 22

Concentrations (mg/kg wet weight) of metals, for which an MPC exists, in tissues of green turtle (*Chelonia mydas*). The MPC values are shown in brackets next to the metals. n = sample size; SD = standard deviation; bdl = below detection limit.

Tissue	n	Value	Total As	Inorg As (1.0)	Cd (0.2)	Cu (10.0)	Hg (0.5)	Pb (1.5)	Se(1.0)	Zn (150.0)
Muscle	7	Mean	1.35	0.018	1.14	4.69	0.02	0.07	0.30	12.48
		SD	1.909	0.025	2.935	11.174	0.011	0.105	0.337	9.018
		Range	0.08-4.8	0.001-0.062	0.01-7.8	0.14-30.0	0.01-0.04	0.02-0.31	0.07-0.96	6.0-27.0
Liver	7	Mean	1.49	0.019	10.73	59.29	0.08	0.59	1.06	38.57
		SD	1.401	0.018	3.437	65.644	0.061	0.461	1.09	9.676
		Range	0.42-4.3	0.005-0.056	6.0-17.0	0.84-180.0	0.02-0.17	0.07-1.1	0.34-3.4	24.0-52.0
Kidney	7	Mean	0.42	0.005	26.0	7.41	0.02	0.07	0.45	23.76
		SD	0.413	0.005	10.939	16.580	0.01	0.037	0.417	3.185
		Range	0.07-1.2	0.0009-0.016	12.0-42.0	0.81-45.0	0.01-0.04	0.05-0.15	0.16-1.3	19.0-28.0
Intestine	7	Mean	7.29	0.095	3.66	0.82	0.03	0.05	0.34	17.54
		SD	18.396	0.239	6.994	0.806	0.042	0.016	0.352	5.525
		Range	0.04-49.0	0.0005-0.637	0.01-19.0	0.15-2.6	0.01-0.12	0.03-0.08	0.09-1.1	8.8-26.0

APPENDIX 23

Mean quantities (in kg) of certain traditional seafoods which if consumed would place the consumer at the levels recommended in the PTWI estimates. Categories of consumer are the same as those used in the Market Basket Survey (Stenhouse 1991; 1992). An empty cell indicates that the levels of metals were low and unlikely to influence comsumption patterns. The single value for selenium (Se) reflects the absence of a weight-related standard.

Food Item	Sample	Tissue	Consumer	As	Cd	Cu	Hg	Pb	Se	Zn
FISHES										
L. calcarifer	Grilled ungutted	Muscle	Man				0.203			
			Woman				0.159			
			Boy				0.112			
			Girl				0.118			
S. dimidiatus	Fresh gutted	Muscle	Man		0.025	1.9				
			Woman		0.021	1.6				
			Boy		0.009	1.0				
			Girl		0.013	1.1				
V. sereli	Grilled ungutted	Gut							0.673	
CRUSTACEANS										
P. ornatus	Boiled	Head	Man		0.222	4.8				
			Woman		0.187	3.8				
			Boy		0.079	2.5				
			Girl		0.117	2.6				

Food Item	Sample	Tissue	Consumer	As	Cd	Cu	Hg	Pb	Se	Zn
Dugong	Fresh	Muscle+fat	Man		15.0	69.7			3.0	
			Woman		12.6	55.7				
			Boy		5.35	36.9				
			Girl		7.9	38.6				
	Fresh	Muscle	Man		20.0	1145.1			8.3	
			Woman		16.8	916.1				
			Boy		7.1	607.3				
			Girl		10.5	633.9				
	Fresh	Liver	Man		0.047	1.3			0.640	
			Woman		0.039	1.0				
			Boy		0.017	0.677				
			Girl		0.025	0.706				
	Fresh	Kidney	Man		0.037	88.0			0.257	
			Woman		0.031	70.4				
			Boy		0.013	46.7				
			Girl		0.019	48.7				
	Fresh	Intestine	Man		3.3	533.5			7.95	
			Woman		2.8	426.8				
			Boy		1.2	282.9				
			Girl		1.7	295.4				

Food Item	Sample	Tissue	Consumer	As	Cd	Cu	Hg	Pb	Se	Zn
Turtle	Fresh	Muscle	Man		0.262	3.9	6.2		0.823	
			Woman		0.220	3.2	3.3			
			Boy		0.093	2.1	2.4			
			Girl		0.138	2.2	2.5			
	Fresh	Liver	Man		0.028	31.7	24.7		1.9	
			Woman		0.023	25.3	13.5			
			Boy		0.010	16.8	9.5			
			Girl		0.015	17.5	10.0			
	Fresh	Kidney	Man		0.011	284.9	19.0		2.6	
			Woman		0.01	227.9	10.4			
			Boy		0.004	151.1	7.3			
			Girl		0.006	157.7	7.7			
	Fresh	Intestine	Man		0.082	50.0	29.1		2.9	
			Woman		0.069	40.0	15.9			
			Boy		0.029	26.5	11.2			
			Girl		0.043	27.7	11.8			

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