The derivation of threshold mean concentrations of copper and zinc in seawater, to protect the edible tropical rock oyster, *Saccostrea cuccullata,* from exceeding the health (food) standards.

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DAMPIER ARCHIPELAGO MARINE STUDY

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ABSTRACT

Threshold mean concentrations in seawater for copper and zinc (0.004 mg/L, and 0.0127 mg/L respectively) have been derived to protect the edible oyster Saccostrea cuccullata from exceeding the NHMRC food standards of 70 and 1000 mg/kg wet weight respectively. The derivation took into account oyster size, water quality, seasonal factors and problems with analytical methodology. The wet to dry weight conversion factor of 3.8 (CV = 21.4%) was independent of both season and oyster size.

1. INTRODUCTION

Water quality criteria are important for the management of aquatic ecosystems. Such criteria permit the formulation of environmental protection policies through which decisions relating to the management of water quality may be made (USEPA 1976). The word "criterion" should not be used as a synonym for the word "standard". A chemical criterion represents a constituent concentration associated with a degree of environmental effect, upon which scientific judgements may be made (USEPA 1980). Water quality criteria are reviewed continually and hence should never be regarded as absolute. They should be used with discretion and with a sound understanding of their development. Water quality criteria will be changed as knowledge and perception of aquatic ecosystems improve, and the understanding of antagonistic and synergistic effects between chemical species in organisms develops.

Criteria used for the protection of aquatic ecosystems are usually derived from toxicological data with the application of a safety factor. The use of such data, however, may not be appropriate where criteria are required for aquatic species used for human consumption. For example, USEPA (1980) has a water quality criterion for Cd of 4.5 ug/L (24 h average value) with no single value to exceed 59 ug/L. Such values are too high when one considers that Rosman et al. (1980) have reported [Cd] of 2.58 ug/L in seawater, and Talbot and Chegwidden (1982) have reported [Cd] in the edible mussel Mytilus edulis to be 5 times greater than the World Health Organisation (WHO) and National Health and Medical Research Councils (NHMRC) guideline of 2 mg/kg wet weight. Additional problems associated with the use of criteria are that many are based on experimental methods which have no universal acceptance, particularly in the case of chemical analyses.

This bulletin reports on [Cu] and [Zn] in the tropical rock oyster Saccostrea cuccullata, in ambient seawater at 8 sites in the Dampier Archipelago (20°20′-20°41′S, 116°42′-116°48′E), north-western Australia (Fig. 1). Special emphasis is given to analytical methodology with consideration of future standardisation. The validity of the use of certain parametric statistics (arithmetic means, $\overline{X}$; coefficient of variation, or relative dispersion, % CV) to summarize the data is also taken

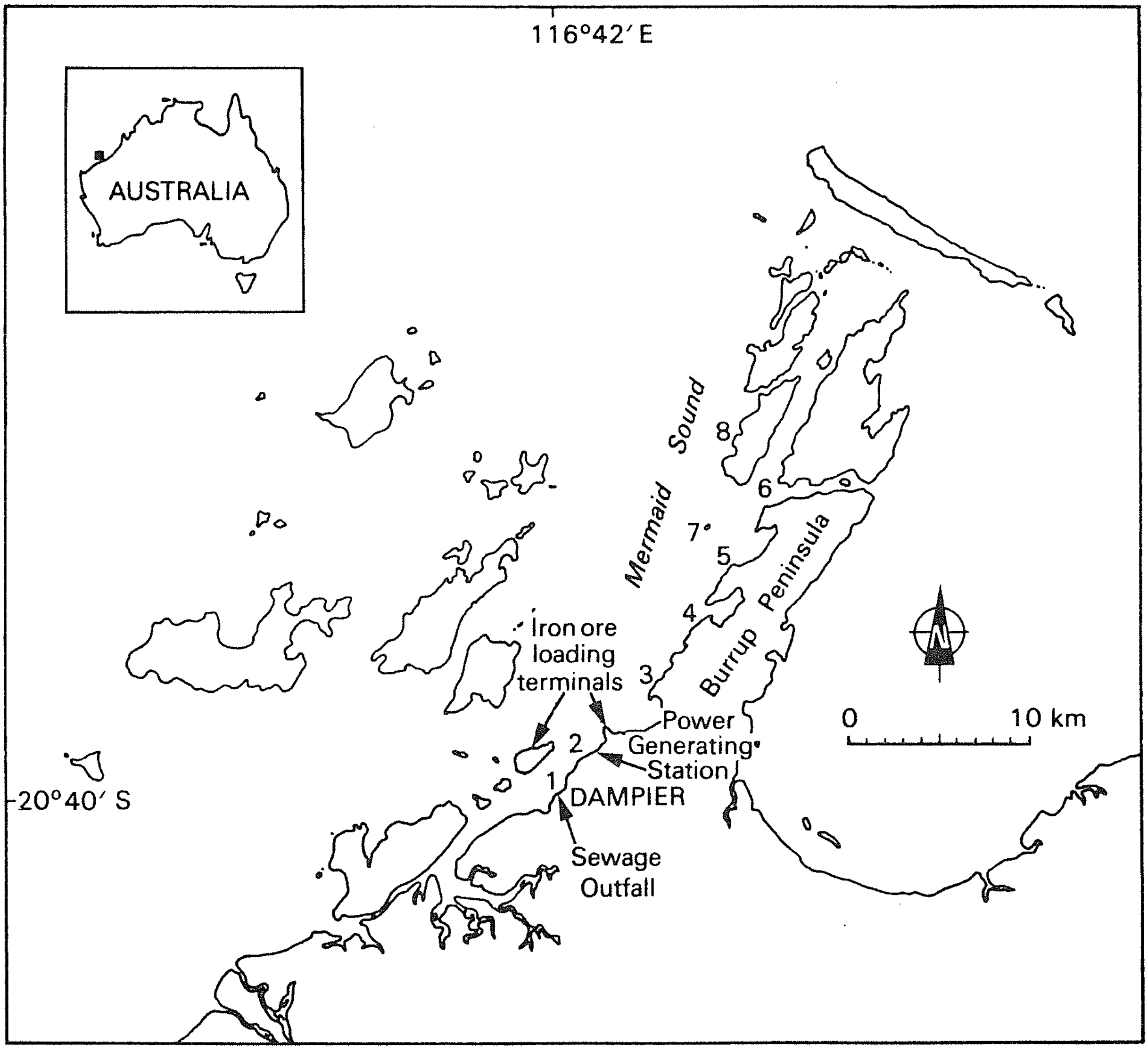

Figure 1. Sampling sites in the Dampier Archipelago.

into account. It has long been recognized that the logarithmic metal concentrations in oysters is nearer the median value than is the arithmetic mean value (Wolfe 1970; Huggett et al. 1973). This difference varies between 3.1 - 10.4% in soft oyster tissue but is relatively small compared with the spread of values used to derive the means (Wolfe 1970; Boyden 1977; Talbot and Simpson 1983). Whilst differences between means may be small they are often critical when comparing data against health standards which are absolute. Statistics used to summarize the data should thus be dictated by the authors' aims rather than by convention (Talbot and Simpson 1983).

Finally, threshold mean concentrations are derived for [Cu] and [Zn] in seawater which, if not exceeded, would ensure that the flesh of this species of oyster did not exceed WHO and NHMRC standards at any time.

2. MATERIALS AND METHODS

2.1 Sampling sites and sampling frequency

Talbot (1985) has previously shown that, in the oyster Saccostrea cuccullata in the vicinity of a sewage discharge and a power generating station near Dampier (Fig. 1), [Cu] and [Zn] approach the NHMRC standards for these metals in foodstuffs. Hence, Site 1 and 2 were selected to be near these effluents. Other sites were chosen principally to collect seawater with the widest range of [Cu] and [Zn] possible within the Archipelago. The availability of oysters (50-55 mm length) and the distance from anthropogenic perturbations were also considered during site selection.

Since the metal content, wet weight and dry weight of oysters are known to vary annually (Wright 1978), eight sampling periods over one year were chosen to gain some understanding of the metal concentrations and loads in this oyster as a function of season.

2.2 Seawater collection and analysis

A single collection container was used for each site for all sampling trips. Prior to each trip, 600 ml polyethylene containers were washed with 200 ml analytical reagent (AR) grade concentrated Mallinckrodt nitric acid (HNO_3), and later rinsed with seawater from the particular site at which they were to be used. Ten 500 ml subsamples were collected at each site in a 600 ml polyethylene bottle placed on a 3 m plastic, tubular extension piece in front of a slow, forward-moving boat, so that only uncontaminated seawater was sampled. Subsamples were then bulked in 5 L storage bottles, acidified with 50 ml AR grade Mallinckrodt HNO_3 and stored frozen prior to analysis.

The seawater was analysed using the solvent extraction methods of Danielsson et al. (1978) and Taylor (1980). The metals were finally taken up in a dilute perchloric acid ($HClO_4$) solution (giving a two hundred fold concentration) and analysed for Cu and Zn using flame atomic - absorption spectroscopy (AAS) (Danielsson *et al.*, 1978).

Whilst the limit of detection for Cu and Zn was 0.00005 mg/L, Taylor (1980) has suggested that the lower quantitative determination (LQD) is a more meaningful value. In this case it was 0.0002 mg/L for both metals.

2.3 Quality control for seawater analysis

As the [Cu] and [Zn] concentrations in seawater are very low, it was imperative to ensure a high degree of quality control :

(1) contamination was minimized by storing all apparatus in 1M HNO_3 and rinsing with distilled water prior to use. All handling of glassware and sample was carried out with polyethylene gloves;

(2) all analyses were carried out in triplicate;

(3) 10% of all analyses were blanks and yielded a CV of 9.1%;

(4) 20% of all analyses included standard samples (0.001 mg/L Cu and Zn) inserted randomly at the predigestion stage. Comparisons between these digested standards and those standards used to calibrate the instruments showed a $\overline{X}$ and CV for the recovery of Cu and Zn of 91.3%, 3.2% and 95.9%, 5.9%, respectively;

(5) 5% of analyses included spiked standard samples (0.001 mg/L Cu and Zn) inserted randomly at the pre-digestion stage of analysis. The $\overline{X}$ and CV for the recovery of Cu and Zn were 94.0%, 5.0% and 98.5%, 7.1%, respectively;

(6) during the four month period of analyses, a batch of randomly selected samples (7% of total number of samples) was reanalysed with each successive batch of samples. Three replicates were used in each instance and, with the exception of two samples, all replicate analyses were reproducible to within 0.0001 mg/L;

(7) flame AAS analysis was cross - checked using direct injection graphite furnace AAS (Varian GTA95 - Hewlett Packard 85), and solvent extraction using this AAS system. Values obtained for Cu from all three methods showed less than + 5% deviation. Zn values recorded using the graphite furnace methods were up to 20% greater than those for flame AAS. This variation, however, is small for such low concentrations of metals encountered *in situ* in relatively unpolluted coastal waters.

2.4 Oyster preparation and chemical analysis

Oysters were cleaned externally using surgical stainless steel blades. Depuration (expulsion of gut contents) prior to analysis was not undertaken for the following reasons :

(1) oysters consumed in Western Australia are seldom held for depurations;

(2) this oyster is an intertidal rock species and normally does not contain a sufficient quantity of mineral components in its gut to affect the analytical results. Preliminary trials determined that the amount of dry weight material purged by this oyster over a 48h period was very low (<<1%) compared with the actual dry weight of the oyster;

(3) when oysters were collected, their shells, which were firmly attached to the substrate, frequently cracked. These damaged oysters tended to die and decompose when allowed to depurate in aerated water. Animals with damaged shells had to be included in order to obtain sufficient sample sizes.

After shucking, the soft flesh was blotted with absorbent paper until no further water was absorbed, and the fresh weight then determined immediately. A range of drying temperatures (90°C-130°C) was initially used; however, no significant difference ($F = 0.6682$, $p<0.05$) was found between final weights of oysters dried at 90°C, 110°C and 130°C and thereafter 110°C was used as the drying temperature (Table 1). The flesh was dried for 24h and allowed to cool in a desiccator for 1h before determining dry weight. Oysters were analysed individually using the method of Talbot and Chegwidden (1982). Results were expressed on a dry weight basis with an appropriate wet to dry weight conversion factor (3.8).

2.5 Contamination : primary and secondary standards

The procedures employed to avoid contamination and to standardize analytical techniques using standard reference material, are the same as those described by Talbot and Chegwidden (1982). Values obtained from the analyses of standard reference materials are given in Table 2.

2.6 Statistical Analyses

To indicate the small differences between arithmetic and geometric means, all data are summarised in Appendix 1. Skewness of data was tested using Pearson's first and second coefficients.

Linear, logarithmic, exponential and power regression coefficients were calculated for the relationship between [Cu] and [Zn] in seawater and in oysters, using the SPSS statistical package developed by Nie et al. (1975). Similar correlations were carried out to describe the relationship between size and [Cu] and [Zn] in oysters (n=200) at site 1. Following this, threshold mean concentrations for the protection of *S. cuccullata* were calculated for [Cu] and [Zn] in seawater from

TABLE 1

% dry weights for 3 subsamples of a homogenised bulk sample of 50 oysters (50-55 mm length) determined at 3 different drying temperatures over a 24hr drying period.

	Drying Temperature 90°C	110°C	130°C
$\bar{X}$ +	26.9	27.1	26.9
Range	26.3 - 27.4	26.1 - 28.3	26.3 - 27.7
C.V.*	1.30	2.29	1.56

\+ Arithmetic mean of 10 determinations

* Coefficient of variance (% relative dispersion)

TABLE 2

A comparison between values obtained from orchard leaves and bovine liver samples, analysed by the techniques used in this study, and those values obtained from NBS standards.

Material	Cu mg/kg dry wt. ($\bar{X}$±SD)	Zn mg/kg dry wt. ($\bar{X}$±SD)
Orchard leaves (NBS#1971)	12±1	25±3
Orchard leaves (20 determinations, this study)	11±3	24±4
Bovine liver (NBS#1577)	193±10	130±10
Bovine liver (10 determinations, this study)	184±16	127±12

the resultant regression line of best fit.

3. RESULTS

3.1 [Cu] and [Zn] in seawater

In seawater mean values for [Cu] ranged from a maximum of 0.0042 mg/L at site 1 to levels approaching the LQD of 0.0002 mg/L at sites 7 and 8 (Table 3). The levels of Cu in seawater at sites 1-3 in the vicinity of both sewage outfall and the power generating station, were generally greater than in seawater from sites further north in Mermaid Sound. A similar pattern was recorded for [Zn], with a range of 0.0190 mg/L at site 1 to 0.0009 mg/L at sites 5, 6 and 8. The CV of the [Cu] ranged between 20.0% (April 84) and 117.4% (June 83) and for [Zn] between 17.8% (April 84) and 46.6% (December 83). For [Cu] the highest CV (117.4%) occurred at site 2, adjacent to the power generating station.

3.2 Oysters

3.2.1 Wet weight/dry weight

Data for oyster wet weights were not highly skewed, and variation between arithmetic and geometric means was $<5\%$. As a result a decision was made to use arithmetic mean ($\bar{X}$) values and CV (or Gaussian statistics) to describe the data.

At all sites the highest arithmetic and geometric mean values for oyster wet weight and dry weight were recorded between October and January (Appendix 1). The greatest rate of increase in wet weight took place from August to October at sites 3-8, while that at site 2, which was more sheltered, occurred between October and December. The greatest rate of decrease in wet weight occurred between January and April.

Frequency distribution analysis of the highest individual values (see range, Appendix 1), highest $\bar{X}$ values, and CV for wet and dry weight as a function of sampling time, showed no strong seasonal correlation. Similarly % dry weight determined for each sampling site showed no seasonal relationship.

Wet to dry weight ratios showed no marked seasonal trends (Appendix 1). A maximum ratio of 4.4 (site 3) was recorded in October 1983, and a minimum ratio of 3.0 (site 4) in April 1983. Annual mean wet to dry weight ratio varied between 3.7-3.9; hence a conversion factor of 3.8 was used in succeeding calculations.

3.2.2 [Cu] and [Zn] in oysters

At most sites [Cu] and [Zn] in oyster flesh reached maximum levels during October 1983, whilst lowest values were recorded during the December 1983 - January 1984 (Appendix 2). Mean

TABLE 3

Summary of 8 Cu and Zn determinations on seawater each made up from 10 subsamples ($mg\ L^{-1}$) at 8 sites in the Dampier Archipelago between April 1983 - April 1984.

Site		1	2	3	4	5	6	7	8
Cu	$\bar{X}$	0.0042	0.0015	0.0004	0.0003	0.0003	0.0003	0.0002	0.0002
	CV%	35.8	117.4	23.3	29.2	30.6	27.3	20.2	20.0
Zn	$\bar{X}$	0.0190	0.0024	0.0016	0.0013	0.0009	0.0009	0.0010	0.0009
	CV%	32.2	29.6	42.3	31.4	31.5	46.6	35.3	17.8

[Cu] values ranged from 285 mg/kg dry weight (site 1, July 1983) to 34 mg/kg dry weight (site 6, December 1983). The highest and lowest annual $\overline{X}$ [Cu] was 228 mg/kg dry weight at site 1 and 46 mg/kg dry weight at site 6. The CV for the annual $\overline{X}$ [Cu] ranged between 22% - 27%.

Mean [Zn] ranged from 4131 mg/kg dry weight (site 2, April 1984) to 210 mg/kg dry weight (site 6, December 1983) with annual $\overline{X}$ values ranging from 2974 mg/kg dry weight at site 1 to 387 mg/kg dry weight at site 6. The CV of annual $\overline{X}$ [Zn] for each site ranged between 22% and 26%.

All metal concentrations were converted into mean loads per specimen. Highest loads for Cu and Zn occurred in October with the exception of Cu and Zn at site 1, Zn at site 2 and Zn at site 4 where the highest values occurred in July, December and April respectively (Table 4). Lowest Cu loads occurred in April 1984 with the exception of Cu at site 6, where it occurred in August and site 7 where it occurred in December as well as April. For Zn the lowest values tended to occur between December 1983 - April 1984 with the exception of sites 1 and 2 where it occurred in June. The reason the trends for Zn and to a lesser extent Cu at sites 1 and 2 differed from those of other sites may be due to their proximity to perturbations. Annual $\overline{X}$ values for Cu ranged from 20 ug to 83 ug while those for Zn ranged from 169 ug to 1066 ug (Table 4).

3.2.3 Relationships between [Cu], [Zn] and oyster length

The relationship between oyster length and [Cu] was best described by :

$$[Cu]_{mg/kg \quad dry\ wt} = 86.6e^{0.016\ length(mm)} \qquad (a)$$

(r=0.458, P<0.001)

The relationship between oyster length and Zn was :

$$[Zn]_{mg/kg \quad dry\ wt} = 1123e^{0.018\ length(mm)} \qquad (b)$$

(r=0.625, P<0.001)

Using the NHMRC standards for Cu and Zn (70 and 1000 mg/kg wet weight, respectively), a wet to dry weight conversion factor of 3.8, and equations (a) and (b), it can be calculated that at site 1, oysters 70 mm and 68 mm in length, will have reached the NHMRC limit for Cu and Zn respectively. From this an approximate threshold mean concentration was gained for each metal.

3.3 <u>Threshold mean concentrations for Cu and Zn in seawater</u>

The maximum length of oyster at site 1 was 77mm, it can be calculated from equation (a) that oysters of this length will contain a mean [Cu] of 296.9 mg/kg dry weight which exceeds the

TABLE 4

Variation in total loads of Cu and Zn (ug) at eight sampling sites between April 1983 - April 1984 : See Appendix 1 for number of individuals used in each calculation

		Sampling Date									
Site	Metal	27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	02.04.84	Annual Mean	
1	Cu $\bar{X}$	91	87	103	72	75	90	88	60	83	% CV 16
2		56	53	61	53	76	62	51	49	57	% CV 10
3		43	49	59	35	74	51	47	25	48	% CV 31
4		40	37	40	34	43	32	37	32	37	% CV 11
5	Cu $\bar{X}$	23	29	26	22	59	19	27	16	28	% CV 49
6		20	19	20	13	38	15	23	14	20	% CV 39
7		31	31	27	40	43	24	28	24	31	% CV 23
8		27	22	26	21	60	30	28	20	30	% CV 44
1	Zn $\bar{X}$	1048	855	1339	1153	1090	1134	858	974	1056	% CV 21
2		1013	959	1104	978	1144	1157	1018	1156	1066	% CV 8
3		640	766	803	577	1186	916	750	490	766	% CV 28
4	Zn $\bar{X}$	692	616	507	581	618	486	535	747	598	% CV 15
5		357	431	344	259	921	247	326	246	391	% CV 57
6		182	184	169	116	316	92	124	170	169	% CV 40
7		385	395	331	499	531	247	259	302	369	% CV 29
8		221	200	194	201	362	187	124	161	206	% CV 34

* Coefficient of variance

NHMRC permitted value of 70 mg/kg wet weight (266 mg/kg dry wt) by 11.6%. This exceedence factor will be taken into acount when determining threshold mean concentration in seawater.

Based on annual data (best fit) means for each parameter, the relationship between [Cu] in oyster (50-55mm in length) and seawater may thus be described by the power equation :

$$[Cu]_{mg/kg\ \ dry\ wt\ oyster} = 1709.3 Cu^{0.3712}\ mg/L\ seawater \qquad (c)$$

$(r=0.8116,\ P<0.01)$

Using this equation and taking account of the exceedence value above, a calculated water quality criterion of 0.0048 mg/L [Cu] is required if oysters of < 77 mm length are not to exceed NHMRC standard. This value however is 14.3% higher than the annual $\overline{X}$ value recorded at site 1 (0.0042 mg/L)(Table 3) where oysters 50-55 mm in length are 16.6% under the NHMRC limit, and those 77 mm in length are 11.6% over the limit. Thus a value of 0.0048 mg/L [Cu] is too high to protect oysters < 77 mm in length. Whilst there is little mathematical logic in lowering the threshold mean concentration value, it should however be less than 0.0042 mg/L. As the difference between the calculated value and this value is small, a reasonable first estimate value of 0.0040 mg/L [Cu] is proposed.

From equation (b) it was estimated that oysters 77 mm in length would have Zn levels 18.2% over the NHMRC standard. Using this value and annual data means for each parameter, it was found that the relationship between [Zn] in oysters (50-55 mm in length) and seawater could be best described by the logarithmic equation :

$$[Zn]_{mg/kg\ dry\ wt\ oysters} = 6448.0 + 765.3\ \ln[Zn]_{mg/kg}\ seawater \qquad (d)$$

$(r=0.8081,\ P<0.01)$

From equation (b) and (d) it was calculated that the water quality criteria for [Zn] should be < 0.0127 mg/L if oysters 77 mm in length are not to exceed NHMRC standard.

4. DISCUSSION

Parametric statistics were employed in analyses as data were not highly skewed and such statistics can give greater flexibility with respect to spatial and temporal comparisons. Parametric statistics are of particular value when results of sample analyses are to be compared with health standards.

4.1 <u>Seawater</u>

[Cu] and [Zn] levels in the waters of the Dampier Archipelago meet previously proposed water quality criteria for waters of Western Australia (Anon, 1981) and California, U.S.A. (Klapow and Schueller, 1977), but are elevated compared with those of oceanic waters (Bruland et al., 1978; Danielsson, 1980; Hart, 1982) (see Table 5). This is more likely to be the result of anthropogenic discharges around the Dampier township rather than natural coastline influences.

4.2 Wet weight/dry weight ratios

Very little is known about the reproductive cycle of this species of tropical oyster, though it is known that tropical species, unlike temperate ones, tend to spawn more than once annually and individuals do not necessarily spawn synchronously (Giese and Pearse, 1979). It is likely then that the general wet weight increase (October to January) and decrease (January to April) observed, corresponds to periods of gametogenesis and spawning, respectively. This indicates that the mean wet weight of a sample of oysters reflects seasonal trends, with the range of values reflecting the variation in the reproductive stage of individuals.

The confusion apparent in the literature, with respect to wet and dry weight determinations, is largely due to inconsistencies of methodology; flesh is sometimes homogenized before weighing (Dare and Edwards, 1975), (Cooper et al., 1982), and rinsed with distilled water (Ayling, 1974; Phillips, 1976). Problems associated with comparing values cited in the literature are further complicated by allometric variations in wet to dry weight ratios of oysters and mussels (Harris et al., 1979), and by seasonal variation in weight of tissue (Dare and Edwards, 1975). Whilst an obvious way to overcome this problem would be to quote all results in terms of dry weight, this has limited value, as health standards for metals in foodstuffs are quoted in terms of wet weight. The variation in analytical techniques (Romeril, 1971; Ayling, 1974; Watling and Watling,1976; D'Silva and Qasim, 1979; Smith, 1981; Klumpp and Burden-Jones, 1982) points to an obvious need for workers in this field to standardize techniques, as well as units of measure, such that meaningful comparisons can be made.

The low relative dispersion of % dry weights found in oysters used in this study demonstrate the consistancy of the analytical procedure used to determine wet and dry weights. On the basis of these results it is recommended that the following points be considered by workers when determining wet and dry weights of shellfish ;

(1) Shellfish should not be allowed to depurate if results are not to be compared with health standards of Western Australia;

(2) All shucked flesh should be washed with distilled water and surface dried using water absorbent paper until no further blotting occurs. After this, the wet weight should be determined as soon as possible;

(3) Unless volatile metals such as mercury, arsenic and

TABLE 5

A comparison of [Cu] and [Zn] in waters of the selected water quality criteria (mg kg^{-1}), with open oceanic waters and the Dampier Archipelago.

	[Cu]	[Zn]	Source
Water Quality Criteria	0.0020	0.0080	Klapow and Schueller, 1977
"	0.0050	0.0200	Anon, 1981
Open Oceans		0.00001-0.0006	Bruland et al., 1978
"	0.00012-0.00063		Danielsson, 1980
"	0.0001-0.0002	0.00001-0.0040	Hart, 1982
Dampier Archipelago	0.0014	0.0035	Present Work

selenium are to be analysed, the wet tissue (up to 5g) should be dried at 110°C for 24 hrs. Tissue should then be cooled in a desiccator prior to dry weight determinations. Digestion without drying eliminates the possibility of volatile low-molecular weight metal species being lost during the drying process.

4.3 Geographical and seasonal variation in [Cu] and [Zn]

The highest [Cu] and [Zn] values were found at sites 1 and 2, which were adjacent to the sewage and power station outfalls and the Dampier township; however, lowest values occurred at sites 5 and 6. Site 6 lies at the interface of a fast flowing body of water (>2ms^{-1} on spring flood tide) which enters Flying Foam Passage and a much less energetic body of water in Boat Passage (D.A. Mills pers comm.). As the water at this site is frequently turbid, a higher concentration of suspended adsorbed metals might be expected, but this is not the case. Values are lower than in water at site 8 where water clarity is high and where there is likely to be greater exchange with oceanic water. Generally levels of [Cu] and [Zn] in both seawater and oyster flesh decreased as distance from sites of sewage outfall and the power generating station increased.

With the exception of site 1, maximum [Cu] found at each site (October) corresponded to, the end of the period of the greatest rate of increase in wet weight, the period of gametogenesis. This may be the result of metabolic changes during gametogenesis which are Cu dependent. With the exception of site 8, the lowest Cu values corresponded to the spawning period, November - January, which may indicate that the material lost during spawning is rich in Cu.

With the exception of site 1 and 7, the maximum [Zn] at each site occurred between October and April when gametogenesis and spawning may be occurring. As tropical oysters can spawn more than once annually, it is not surprising that the maximum metal concentrations varies temporally between sites. Whilst it is unlikely that Cu and Zn follow the same metabolic pathways within the oyster, a proportion of the total loads of these two chemically similar metals may be at similar sites within the animal and hence show some common seasonal variation pattern.

The Cu and Zn loads follow similar seasonal trends as the actual concentrations. This would not be the case if the change in concentration was solely a function of a change in wet weight during gametogenesis as Boyden (1974) has demonstrated for several species of mollusc. Hence, it is conceivable that an excretion mechanism operates in these oysters which is seasonally dependent.

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APPENDIX 1

Statistics of the wet weight, dry weight, ratio of wet to dry weight and percentage dry weight of the oyster, Saccostrea cucculata, 50-55 mm length sampled eight times between April 1983 and April 1984 at eight stations in the Dampier Archipelago.

SITE		27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	20.01.84	02.04.84	Annual mean
		Wet Weight								
1	$\bar{X}$	1.32	1.44	1.42	1.40	1.33	1.45	2.07	1.20	1.45
	Range	1.09-1.78	1.04-2.03	1.09-1.96	0.98-2.03	1.11-1.76	1.08-2.10	1.47-2.87	0.86-1.63	
	CV	17.9	21.6	19.4	23.2	17.9	18.6	26.3	22.1	20.88
	G	1.20	1.32	1.36	1.32	1.27	1.37	1.93	1.14	1.35
	N*	30	30	30	30	30	30	30	30	
		Dry Weight								
1	$\bar{X}$	0.34	0.36	0.36	0.36	0.34	0.41	0.53	0.27	0.37
	Range	0.29-0.38	0.33-0.39	0.32-0.40	0.31-0.38	0.30-0.39	0.37-0.44	0.49-0.56	0.24-0.32	
	CV	16.3	18.7	21.4	17.9	23.8	21.6	22.7	24.3	20.84
	G	0.30	0.32	0.33	0.32	0.31	0.36	0.48	0.26	0.33
		Wet to dry weight ratio								
1	$\bar{X}$	3.9	4.0	3.9	3.9	3.9	3.5	3.9	4.4	3.9
		%dry weight								
1	$\bar{X}$	25.7	25.0	25.4	25.5	25.6	26.3	25.6	22.8	25.2
	Range	24.7-29.4	22.8-27.6	21.9-28.3	22.6-28.4	22.7-27.9	23.6-28.9	22.8-27.7	19.9-24.6	
	CV	4.9	5.3	6.4	6.2	8.1	3.7	4.8	7.3	5.8
	G	25.0	24.3	24.3	24.2	24.4	26.3	24.9	22.5	24.5
		Wet weight								
2	$\bar{X}$	1.56	1.48	1.40	1.19	1.38	1.73	1.85	1.21	1.24
	Range	0.98-1.93	1.03-2.10	0.89-2.16	0.36-1.53	1.10-1.93	1.19-2.46	1.35-2.46	0.73-1.75	
	CV	20.5	21.6	27.1	24.3	18.1	21.4	18.4	21.5	21.6
	G	1.54	1.46	1.38	1.17	1.37	1.68	1.82	1.18	
	N	30	30	30	30	30	30	30	30	
		Dry weight								
	$\bar{X}$	0.42	0.39	0.38	0.31	0.37	0.42	0.48	0.28	0.38
	Range	0.38-0.59	0.35-0.47	0.36-0.46	0.24-0.44	0.28-0.54	0.30-0.52	0.33-0.65	0.16-0.46	
	CV	18.8	17.9	34.2	29.0	21.6	23.8	18.8	25.0	23.6
	G	0.41	0.38	0.36	0.30	0.36	0.39	0.47	0.27	

Column group: SAMPLING DATES.

SITE		27.04.84	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	02.04.84	Annual Mean
					SAMPLING DATES					
					Wet to dry weight ratio					
2	$\bar{X}$	3.7	3.8	3.7	3.8	3.7	4.1	3.9	4.3	3.9
					% dry weight					
	$\bar{X}$	27.2	26.3	26.7	24.4	26.5	25.5	25.7	22.8	25.6
	Range	24.8-29.6	24.1-28.3	23.6-29.5	23.6-31.0	26.2-28.0	22.9-28.3	22.5-29.2	18.0-26.7	
	CV	5.1	5.6	7.8	9.6	3.5	6.6	8.1	11.0	7.1
	G	27.2	26.1	26.6	26.3	26.5	25.5	25.6	22.7	
					Wet weight					
3	$\bar{X}$	1.40	1.57	1.48	1.18	1.64	1.55	1.78	0.91	1.44
	Range	0.96-2.31	0.89-2.46	0.75-2.18	0.73-1.63	0.93-2.19	1.15-2.23	1.05-2.66	0.69-1.38	
	CV	35.7	21.7	33.1	21.2	37.2	21.3	27.5	25.3	27.9
	G	1.38	1.56	1.46	1.15	1.57	1.52	1.72	0.89	
	N	27	22	26	27	18	21	19	34	
					Dry weight					
3	$\bar{X}$	0.39	0.44	0.41	0.31	0.37	0.44	0.48	0.25	0.39
	Range	0.24-0.67	0.23-0.61	0.20-0.53	0.15-0.45	0.19-0.58	0.27-0.57	0.26-0.72	0.16-0.34	
	CV	35.9	34.1	34.1	25.8	37.8	25.0	27.1	20.0	30.0
	G	0.37	0.43	0.38	0.30	0.34	0.42	0.46	0.24	
					Wet to dry weight ratio					
3	$\bar{X}$	3.6	3.6	3.6	3.8	4.4	3.8	3.7	3.6	3.7
					% dry weight					
3	$\bar{X}$	27.9	27.6	27.5	26.4	22.1	27.9	26.9	27.6	26.7
	Range	21.3-30.3	24.3-28.4	21.5-30.6	20.6-29.1	16.7-30.4	23.2-30.4	24.7-32.5	32.2-38.5	
	CV	11.5	8.7	13.1	11.5	18.6	10.0	9.3	14.5	12.2
	G	27.7	27.6	27.4	26.3	21.8	27.8	26.7	24.4	
					Wet weight					
4	$\bar{X}$	1.33	1.36	1.23	1.07	1.29	1.47	1.69	1.17	1.33
	Range	0.79-2.64	0.89-2.13	0.71-2.44	0.62-2.11	0.89-1.74	0.73-1.96	1.00-2.40	0.73-1.90	
	CV	42.1	39.0	39.8	29.9	24.0	20.4	23.7	29.1	31.0
	G	1.31	1.33	1.16	1.03	1.25	1.43	1.65	1.13	
	N	29	25	28	28	23	27	24	32	
					Dry weight					
4	$\bar{X}$	0.37	0.34	0.33	0.27	0.33	0.43	0.44	0.31	0.35
	Range	0.19-0.68	0.20-0.66	0.18-0.60	0.17-0.47	0.18-0.50	0.21-0.57	0.28-0.69	0.21-0.44	
	CV	46.5	28.2	39.4	33.3	30.3	23.3	31.8	22.6	31.9
	G	0.34	0.32	0.30	0.26	0.32	0.41	0.42	0.30	
					Wet to dry weight ratio					
4	$\bar{X}$	3.0	4.0	3.7	4.0	3.9	3.4	3.8	3.8	3.8

SITE		27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	02.04.84	Annual Mean
						SAMPLING DATES				
						% dry weight				
4	$\bar{X}$	27.5	25.2	27.2	25.3	25.8	28.9	25.7	26.6	26.5
	Range	24.1-31.0	22.3-29.6	22.1-34.0	22.1-27.5	20.9-30.2	26.2-31.8	17.8-33.1	22.1-37.3	
	CV	8.7	11.1	14.0	7.1	10.5	6.6	14.8	15.4	11.0
	G	27.4	25.0	26.9	25.3	25.7	28.8	25.4	26.4	
						Wet weight				
5	$\bar{X}$	1.30	1.58	1.30	1.11	1.92	1.52	1.64	1.18	1.44
	Range	0.83-1.87	0.84-2.11	0.93-1.76	0.84-1.64	1.25-2.93	1.12-1.88	0.92-2.28	0.74-1.82	
	CV	26.9	26.6	20.8	23.4	30.2	17.1	22.0	31.4	24.8
	G	1.26	1.55	1.28	1.09	1.84	1.50	1.60	1.13	
	N	29	26	22	19	28	21	26	31	
						Dry weight				
5	$\bar{X}$	0.36	0.41	0.36	0.33	0.48	0.44	0.45	0.33	0.40
	Range	0.24-0.55	0.28-0.52	0.24-0.48	0.22-0.52	0.34-0.74	0.31-0.59	0.28-0.58	0.11-0.46	
	CV	30.6	29.3	27.8	27.3	27.1	20.5	20.0	30.0	26.6
	G	0.35	0.38	0.34	0.32	0.47	0.44	0.44	0.31	
						Wet to dry weight ratio				
5	$\bar{X}$	3.6	3.9	3.6	3.4	4.0	3.5	3.6	3.6	3.7
						% dry weight				
5	$\bar{X}$	27.8	25.4	27.6	29.5	25.4	28.5	27.8	27.8	27.5
	Range	21.2-31.3	20.2-29.6	19.4-33.2	25.5-32.2	21.2-29.6	24.3-32.1	24.2-32.6	18.7-45.9	
	CV	9.7	9.6	15.1	7.7	11.1	8.7	9.4	20.3	11.5
	G	27.6	25.3	27.3	29.4	25.3	28.4	27.7	27.4	
						Wet weight				
6	$\bar{X}$	1.42	1.48	1.56	1.07	2.08	1.62	2.00	1.30	1.57
	Range	0.94-2.14	0.89-2.06	0.97-2.84	0.47-1.20	0.89-3.41	1.39-1.82	1.15-3.38	0.70-2.51	
	CV	21.1	22.3	37.2	39.3	39.4	9.3	29.5	50.0	31.0
	G	1.39	1.46	1.47	1.01	1.93	1.61	2.07	1.16	
	N	18	24	23	19	17	18	21	20	
						Dry weight				
6	$\bar{X}$	0.41	0.40	0.45	0.28	0.56	0.44	0.57	0.34	0.43
	Range	0.27-0.58	0.23-0.59	0.22-0.84	0.12-0.63	0.26-0.99	0.36-0.58	0.33-0.85	0.14-0.63	
	CV	22.0	45.0	40.0	46.4	42.9	15.9	26.3	58.8	37.2
	G	0.40	0.38	0.42	0.26	0.52	0.44	0.55	0.29	

SITE		27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	02.04.84	Annual Mean
		SAMPLING DATES								
		Wet to dry weight ratio								
6	$\bar{x}$	3.5	3.7	3.5	3.8	3.7	3.7	3.5	3.8	3.4
		% dry weight								
6	$\bar{x}$	28.9	27.0	28.5	26.2	26.8	27.5	27.7	25.4	27.3
	Range	26.0-32.7	25.9-29.8	21.6-33.1	22.7-29.0	24.4-29.2	20.3-31.7	25.4-31.6	17.0-34.4	
	CV	7.1	8.6	9.4	9.0	6.7	13.7	6.8	19.8	10.1
	G	28.8	26.9	28.4	26.1	26.7	27.2	27.6	24.9	
		Wet weight								
7	$\bar{x}$	1.37	1.32	1.22	1.46	1.87	1.55	1.39	1.22	1.43
	Range	1.10-1.69	0.99-1.68	0.71-1.68	0.96-2.44	1.49-2.40	0.99-2.13	0.91-1.72	0.46-2.07	
	CV	13.1	14.4	25.4	27.4	18.7	20.6	18.0	32.8	21.3
	G	1.36	1.28	1.17	1.41	1.85	1.52	1.37	1.14	
	N	28	23	29	22	27	23	21	33	
		Dry weight								
7	$\bar{x}$	0.37	0.36	0.32	0.40	0.43	0.42	0.35	0.33	0.37
	Range	0.22-0.46	0.21-0.47	0.17-0.43	0.23-0.63	0.32-0.59	0.30-0.55	0.22-0.46	0.11-0.55	
	CV	18.9	27.7	25.0	27.5	20.9	23.8	20.0	33.3	24.6
	G	0.37	0.34	0.31	0.38	0.42	0.40	0.34	0.30	
		Wet to dry weight ratio								
7	$\bar{x}$	3.7	3.7	3.8	3.7	4.3	3.7	4.0	3.7	3.8
		% dry weight								
7	$\bar{x}$	27.0	26.7	25.9	27.2	23.0	26.9	25.1	26.8	26.1
	Range	17.5-30.8	19.9-28.3	23.0-28.1	24.0-30.5	19.6-27.0	18.2-33.1	22.3-29.0	16.2-40.5	
	CV	14.1	10.9	12.7	8.8	10.0	14.9	7.6	17.9	12.1
	G	26.7	26.5	25.9	27.1	22.9	26.5	25.0	26.4	
		Wet weight								
8	$\bar{x}$	1.45	1.33	1.42	1.26	1.76	1.58	1.39	1.02	1.40
	Range	0.96-2.05	0.89-1.99	0.90-1.96	0.74-1.70	1.09-2.77	1.04-2.34	1.02-1.74	0.60-1.83	
	CV	25.5	27.1	22.5	26.2	29.5	20.3	13.7	28.4	24.2
	G	1.41	1.29	1.34	1.22	1.69	1.55	1.37	0.98	
	N	25	28	16	21	25	31	18	33	
		Dry weight								
8	$\bar{x}$	0.35	0.32	0.38	0.32	0.41	0.40	0.33	0.25	0.[illegible]5
	Range	0.25-0.57	0.26-0.39	0.21-0.46	0.20-0.42	0.28-0.65	0.23-0.55	0.21-0.55	0.11-0.53	
	CV	28.6	28.1	26.3	25.0	29.3	20.0	15.0	32.5	25.5
	G	0.36	0.29	0.35	0.31	0.40	0.39	0.33	0.24	
		Wet to dry weight ratio								
8	$\bar{x}$	4.1	4.2	3.7	3.9	4.3	4.0	4.2	4.1	4.1

SITE		SAMPLING DATES 27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	02.04.84	Annual Mean
		% dry weight								
8	$\bar{X}$	25.6	23.9	26.4	25.2	23.4	25.3	24.1	24.9	24.9
	Range	22.9-29.5	21.8-28.7	23.3-33.1	20.0-29.2	20.9-26.3	22.1-28.7	20.6-27.5	17.2-32.1	
	CV	9.2	9.2	11.1	9.6	7.2	6.6	8.8	15.4	9.6
	G	25.5	23.7	26.0	25.0	23.4	25.3	24.0	24.6	

\+ Coefficient of variance (% relative dispersion)

* Geometric mean

#N Number of specimens analysed

APPENDIX 2

Concentrations of Cu and Zn (mg/kg dry weight) in the oyster <u>Saccostrea cucullata</u> at eight sampling sites in the Dampier Archipelago on eight occasions between April 1983 and April 1984 : See Appendix 1 for number specimens sampled on each occasion.

SITE	METAL		27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	06.04.84	Annual Mean value
1	Cu	$\bar{X}$	268	242	285	200	222	220	166	223	228
		Range	229-308	203-276	245-319	156-259	174-253	111-273	139-186	184-264	
		CV	19	22	29	27	26	31	23	24	25
		G	236	229	267	184	206	203	151	213	209
2	Cu	$\bar{X}$	133	137	160	172	204	149	107	155	152
		Range	67-188	64-218	94-245	143-201	182-246	115-236	88-129	105-256	
		CV	28	34	28	15	13	28	13	29	24
		G	118	130	151	170	203	145	107	149	144
3	Cu	$\bar{X}$	110	111	144	113	200	115	97	100	124
		Range	62-181	68-179	75-210	104-122	139-273	65-169	69-111	80-134	
		CV	24	27	33	9	26	30	26	22	25
		G	106	105	136	113	195	111	95	99	117
4	Cu	$\bar{X}$	108	109	121	125	130	75	83	105	107
		Range	54-164	46-210	77-154	120-143	81-164	63-90	70-96	62-129	
		CV	32	33	23	10	22	15	16	24	22
		G	103	101	118	121	98	74	82	100	99
5	Cu	$\bar{X}$	63	71	72	65	123	44	60	48	68
		Range	47-98	48-95	55-94	54-94	77-128	37-47	53-89	34-67	
		CV	25	21	19	25	36	9	25	27	23
		G	61	68	70	64	118	43	57	42	62
6	Cu	$\bar{X}$	48	47	45	45	68	34	40	42	46
		Range	25-79	26-69	39-52	35-56	34-100	25-38	34-43	35-56	
		CV	31	30	13	18	35	15	10	21	22
		G	46	46	45	44	64	34	40	42	45

SITE	METAL		27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	06.04.84	Annual Mean value
			SAMPLING DATES								
7	Cu	$\bar{X}$	84	87	83	99	101	57	80	73	83
		Range	41-209	53-139	67-125	84-121	93-115	51-67	58-101	51-114	
		CV	57	41	29	16	12	11	20	30	27
		G	74	79	80	98	100	57	79	69	78
8	Cu	$\bar{X}$	76	70	68	67	147	76	85	81	84
		Range	51-138	50-109	42-81	51-78	113-171	62-119	59-107	58-107	
		CV	39	21	24	18	16	24	22	21	23
		G	70	6	60	67	145	70	83	79	77
1	Zn	$\bar{X}$	3083	2374	3720	3204	3208	2766	1618	3606	2947
		Range	2694-3806	1893-2768	2940-4031	2647-3673	2781-3697	2344-3263	1186-2374	2957-4031	
		CV	26	23	28	19	21	18	19	25	22
		G	2852	2243	3681	3048	3067	2609	1507	3551	2729
2	Zn	$\bar{X}$	2412	2460	2906	3151	3092	2755	2122	4131	2879
		Range	1273-4039	1321-3987	2333-3596	2482-4082	1959-4200	2032-3993	1985-2272	3055-5216	
		CV	35	34	12	18	32	29	6	17	23
		G	2281	2236	2860	3111	2955	2667	2119	4078	2731
3	Zn	$\bar{X}$	1641	1741	1958	1862	3205	2082	1562	1962	2002
		Range	933-2317	1203-2210	1348-2479	1645-2672	2571-4343	1331-3607	888-1654	1647-2457	
		CV	27	19	29	8	21	37	41	25	26
		G	1597	1684	1894	1856	3155	1972	1463	1911	1892
4	Zn	$\bar{X}$	1870	1813	1536	2152	1873	1131	1217	2410	1750
		Range	727-2358	963-2431	1130-1935	1575-2800	842-2386	866-1307	971-1467	1699-2874	
		CV	27	28	21	22	34	14	16	19	23
		G	1780	1703	1505	2109	1758	1118	1205	2386	1648
5	Zn	$\bar{X}$	992	1065	956	784	1918	562	725	747	989
		Range	840-1321	844-1509	788-1304	717-817	1340-3009	392-764	418-1015	569-1103	
		CV	17	19	22	6	35	23	30	25	22
		G	972	1037	938	783	1836	547	696	730	885

SITE		SAMPLING DATES 27.04.83	06.06.83	20.07.83	30.08.83	18.10.83	06.12.83	30.01.84	06.04.84	Annual Mean value
6 Zn	$\bar{X}$	444	460	375	414	564	210	212	491	387
	Range	301-608	398-649	290-465	373-448	392-784	154-254	162-319	319-815	
	CV	30	23	18	8	22	17	26	34	22
	G	419	443	369	413	461	207	206	471	357
7 Zn	$\bar{X}$	1041	1096	1034	1247	1235	589	739	916	987
	Range	793-1318	790-1431	840-1376	1138-1350	988-1571	434-840	431-1173	670-1397	
	CV	22	30	24	9	24	28	36	28	25
	G	1008	1053	1013	1243	1212	572	699	887	933
8 Zn	$\bar{X}$	631	624	510	629	883	467	377	642	595
	Range	350-863	321-798	399-609	479-843	549-1064	385-627	285-553	467-919	
	CV	21	21	15	19	27	25	29	22	25
	G	603	590	463	620	855	451	323	629	546

\+ Coefficient of variance (% relative dispersion)

* Geometric mean