

CONTENTS

SUMMARY	xiii
INTRODUCTION	1
PART 1	
1. METAL LEVELS IN TORRES STRAIT PRAWNS	5
1.1 Background	5
1.2 Methods	5
1.2.1 Sample Handling Protocols	6
Collection	6
Sample Selection	6
Moult Staging	7
Dissections	7
Industry Samples	7
1.2.2 Laboratory Analysis	7
1.2.3 Statistical Analysis	8
Pooling and Power	9
1.2.4 Arsenic Conversion	9
1.3 Results	10
1.3.1 Overview	10
1.3.2 Patterns with Prawn Size	20
1.3.3 Patterns with Tissue Type	24
1.3.4 Patterns with Sex	29
1.3.5 Patterns with Moult Stage	31
1.3.6 Patterns with Processing and Handling	33
1.3.7 Spatial Patterns	37
1.3.8 Seasonal Patterns	41
1.4 Discussion	46
1.4.1 Prawn Metal Levels in the Context of Previous Studies	46
1.4.2 Metal Distribution Among Tissues	47
1.4.3 Spatial Variation	48
1.4.4 Seasonal Variation	49
1.4.5 Manageable Factors and their Affect on Metal Levels in Tail Flesh	49
1.4.6 Biotic Factors	49
Age and Growth	49
Sex	50
Moult Stage	50
Other Species	50
1.4.7 Handling Methods	51
1.4.8 The Context of Trade Limits and Human Health	52
1.4.9 Recommendations for Further Work	53

PART 2

2. METAL LEVELS IN THE TORRES STRAIT COMMERCIAL CRAYFISH

<i>Panulirus ornatus</i>	57
2.1 Background	57
2.2 Methods	57
2.2.1 Sample Handling Protocols	57
Collection	57
Industry Samples	58
Dissections	58
2.2.2 Laboratory Analysis	58
2.2.3 Statistical Analysis	59
2.2.4 Arsenic Conversion	59
2.3 Results	59
2.3.1 Overview	59
2.3.2 Spatial and Seasonal Patterns	62
2.3.3 Patterns with Sex	78
2.3.4 Patterns with Handling Methods	79
2.4 Discussion	82
2.4.1 Factors Affecting Metal Levels in Crayfish	83
Size	84
Spatial and Temporal Patterns	84
Sex	85
Industry Handling	85
2.4.2 Recommendations for Further Research	86
APPENDIX 1 Heavy Metals in <i>Penaeus esculentus</i> in Torres Strait Pilot Study	87
APPENDIX 2 Metal Levels in <i>Penaeus esculentus</i> - Normality of Data	91
APPENDIX 3 Procedures Used by Queensland Department of Primary Industry (Animal Research Institute) for Trace Metal Analysis of Biological Samples	97
APPENDIX 4 Models for Analysis of Variance	99
REFERENCES	107

TABLES

1.	Overview of metal levels found in <i>P. esculentus</i> , <i>M. endeavouri</i> and <i>P. longistylus</i> in the present study.	12
2.	Comparative data from previous studies of metal levels in related species of prawns.	13
3.	Total burden of metals in different tissues and whole prawn for <i>P. esculentus</i> , published estimates of maximum advisable weekly intakes, dietary requirements and dietary intakes.	19
4.	Relationship between wet and dry weights for different tissues of <i>Penaeus esculentus</i> and tail muscle in <i>Metapenaeus endeavouri</i> and <i>P. longistylus</i> .	19
5.	ANOVA summary - analysis of differences between metal levels in tail flesh of medium and small <i>P. esculentus</i> at the northern site.	21
6.	Power analysis for non significant size effects in Table 5.	21
7.	ANOVA summary for comparison between metal levels in tail flesh of medium and large <i>P. esculentus</i> at the Southern site.	22
8.	Power analysis for non significant size effect results in Table 6.	23
9.	ANOVA summary for comparison between tissue types and sites for medium sized <i>P. esculentus</i> .	25
10.	Power analysis for results of metals for which there were no significant results involving tissue type.	25
11.	Power analysis for results of metals for which there were no significant results involving site.	26
12.	ANOVA summary for comparison between male and female medium sized <i>P. esculentus</i> tail flesh from the southern site.	30
13.	Power analysis for non significant results involving the fixed factor sex.	30
14.	ANOVA summary for comparison between metal levels in tail flesh from pre- and post-moult medium sized female <i>P. esculentus</i> from the southern site.	32
15.	Power analysis for moult stage F tests, where all tests involving moult stage were non significant.	32
16.	ANOVA summary for tests of the effect of different handling methods on metal levels in tail flesh of medium sized <i>P. esculentus</i> from the southern site.	35

17.	Power analysis for F tests for the effect of handling treatment, where all tests including this factor were non significant.	35
18.	ANOVA summary for comparison between metal levels in tail flesh of <i>P. esculentus</i> , <i>M. endeavouri</i> and <i>P. longistylus</i> from both the northern and southern sites.	38
19.	Power analysis of F tests for site, where all tests including this factor were non significant.	38
20.	Power analysis of F tests for species, where all tests including this factor were non significant.	39
21.	ANOVA summary for the inter-season comparison of metal levels in tail flesh of <i>P. esculentus</i> , <i>P. longistylus</i> and <i>M. endeavouri</i> from the northern site.	42
22.	Power analysis of F tests for season, where all tests including this factor were non significant.	42
23.	Power analysis of F tests for species, where all tests including this factor were non significant.	43
24.	Overview of metal levels found in <i>Panulirus ornatus</i> in the present study.	60
25.	Sample sizes of collections from June and October 1992, across locations, sites and size categories.	63
26.	ANOVA summary for differences in metal concentration in tail flesh of <i>P. ornatus</i> collected in June 1992 at locations Cape York, Dungeness Reef and southern Orman Reefs.	66
27.	Power analysis of non significant location results in Table 25.	66
28.	ANOVA summary for differences in metal concentration in tail flesh of <i>P. ornatus</i> collected in October/November 1992 at Cape York, Dungeness Reef and Kakope Reef.	67
29.	Power analysis of fixed factor non significant results in Table 27.	67
30.	ANOVA summary for seasonal differences in metal concentration in tail flesh of <i>P. ornatus</i> collected from Cape York and Dungeness Reef.	68
31.	Power analysis for fixed factor non significant results in Table 29.	68
32.	Power analysis for non significant sex results.	79
33.	ANOVA summary - analysis of the effect of handling on metal levels in <i>P. ornatus</i> tail flesh, between sites south at Orman Reef.	81
34.	Power analysis for non significant results for treatment F tests.	81

FIGURES

1.	Map of Torres Strait, showing prawn sampling sites (shaded).	4
2.	Box and whisker plots of levels of metals for which there is an Australian NHMRC MPC.	14
3.	Pie diagrams showing the relative contribution of different tissues to total metal load in <i>Penaeus esculentus</i> , for metals included in table 3.	18
4.	Size x night interactions in chromium and zinc levels in <i>P. esculentus</i> tail flesh, between small and medium prawns at the northern site.	22
5.	Effect of size on mercury, selenium and arsenic levels in tail flesh from medium and large <i>P. esculentus</i> , from the southern site.	23
6.	Interaction between size and night in levels of cadmium in tail flesh of medium and large <i>P. esculentus</i> from the southern site.	24
7.	Levels of aluminium (Al), arsenic (As), (Total, iron (Fe)), cobalt (Co) and uranium (U) in different tissues of <i>P. esculentus</i> .	26
8.	Levels of silver (Ag), cadmium (Cd), copper (Cu) and mercury (Hg) in different tissues of <i>P. esculentus</i> from different sampling nights.	27
9.	Levels of chromium (Cr), manganese (Mn), nickel (Ni), selenium (Se), strontium (Sr) and zinc (Zn) in different tissues of <i>P. esculentus</i> from the northern and southern sites.	28
10.	Levels of arsenic (As) in <i>P. esculentus</i> tissues from the northern and southern sites.	29
11.	Levels of strontium across sex, for tail flesh from medium sized <i>P. esculentus</i> from the southern site.	29
12.	Levels of selenium (Se) and mercury (Hg) across sex and night, for tail flesh of medium sized <i>P. esculentus</i> from the southern site.	31
13.	Levels of strontium, copper and zinc in tail flesh of female medium <i>P. esculentus</i> from the southern site, across the moult stage.	33
14.	Levels of cadmium (Cd), copper (Cu), iron (Fe) and strontium (Sr) in tail flesh of medium sized <i>P. esculentus</i> from the southern site, across handling methods.	34
15.	Levels of selenium, chromium, zinc and manganese in tail flesh of medium sized <i>P. esculentus</i> from the southern site, across handling method and sampling night.	36

16.	Mean levels of zinc and mercury in tail flesh of <i>P. esculentus</i> (n=41), <i>M. endeavouri</i> (n=41) and <i>P. longistylus</i> (n=38).	39
17.	Mean levels of arsenic, iron and strontium in tail flesh of <i>P. esculentus</i> (n=20 north, N=21 south), <i>M. endeavouri</i> (n=20 north, n=21 south) and <i>P. longistylus</i> (n=19 north and south), across sites.	39
18.	Mean levels of cadmium, chromium, manganese, nickel, lead and selenium in tail flesh of <i>P. esculentus</i> , <i>M. endeavouri</i> and <i>P. longistylus</i> , across sampling nights.	40
19.	Levels of arsenic, cadmium, copper and mercury in tail flesh of <i>P. esculentus</i> , <i>P. longistylus</i> and <i>M. endeavouri</i> , from the northern site and both pre- and post-wet season sampling.	43
20.	Interseasonal differences in levels of iron, manganese, nickel, selenium and zinc in tail flesh of <i>P. esculentus</i> , <i>P. longistylus</i> and <i>M. endeavouri</i> , from the northern site.	44
21.	Seasonal differences in strontium levels in tail flesh of <i>P. esculentus</i> (n=30 pre wet, n=21 post wet), from the northern site.	45
22.	Seasonal differences in chromium levels in tail flesh of prawns from the northern site.	45
23.	Map of Torres Strait, showing crayfish sampling sites (shaded).	56
24.	Box and whisker plots of levels of metals for which there is an Australian NHMRC MPC.	61
25.	Frequency histogram of crayfish tail widths collected from different locations in June 1992.	69
26.	Frequency histogram of crayfish tail widths collected from different locations in October 1992.	69
27.	Aluminium levels in crayfish tails collected from different sites and locations in June 1992.	70
28.	Seasonal differences in aluminium levels (dry weight basis) in crayfish tails collected from Cape York and Dungeness Reefs.	70
29.	Tail width Vs mean arsenic levels, with standard error bars, in tail flesh of crayfish sampled at Cape York, Dungeness and South Orman sites in June 1992.	70
30.	Tail width Vs mean arsenic levels, with standard error bars, in tail flesh of crayfish sampled at Cape York and Dungeness sites in June 1992 and October 1992.	71
31.	Tail width Vs mean cadmium levels, with standard error bars, in tail flesh of crayfish sampled in June 1992.	71
32.	Overall locational differences in cadmium levels (means with standard error bars) in crayfish tails collected from June and October 1992.	71

33.	Site differences in chromium levels (dry weight basis) in crayfish tails collected in June 1992.	72
34.	Chromium levels (means and standard error bars) in crayfish tails collected in June 1992 excluding South Orman samples, two sites at South Orman in June 1992 and all locations in October 1992.	72
35.	Tail width Vs copper levels in tail flesh of crayfish collected from Cape York and Dungeness sites in June 1992.	73
36.	Tail width Vs copper levels in tail flesh of crayfish collected from Cape York and Dungeness sites in October 1992.	73
37.	Tail width Vs mean iron levels, with standard error bars, in tail flesh of crayfish sampled from Cape York, Dungeness and Kakope sites in October 1992.	74
38.	Iron levels in crayfish tails from Cape York and Dungeness sites collected from both sampling periods combined.	74
39.	Tail width Vs mean manganese levels, with standard error bars, in tail flesh of crayfish collected from all sites in both June and October 1992.	74
40.	Tail width Vs mean selenium levels, with standard error bars, in tail flesh of crayfish collected from all sites in June 1992.	75
41.	Tail width Vs mean nickel levels, with standard error bars, in tail flesh of crayfish collected from all sites in October 1992.	75
42.	Tail width Vs nickel levels in tail flesh of crayfish collected in June and October 1992 combined, from Cape York and Dungeness sites.	75
43.	Inter-site variation in lead levels in tail flesh of crayfish collected in June 1992.	76
44.	Seasonal variation in lead levels in tail flesh of crayfish collected from Cape York and Dungeness.	76
45.	Inter-site variation in zinc levels in tail flesh from crayfish collected in June 1992.	76
46.	Tail width Vs mean zinc levels, with standard error bars, in tail flesh of crayfish collected from all sites in June 1992.	77
47.	Tail width Vs mean zinc levels, with standard error bars, in tail flesh of crayfish collected from all sites in October 1992.	77
48.	Seasonal variation in zinc levels in tail flesh of crayfish from Cape York and Dungeness sites combined.	78
49.	Differences in lead levels in tail flesh of <i>P. ornatus</i> between industry product and cleanly handled research samples.	80
50.	Differences in strontium levels in tail flesh of <i>P. ornatus</i> between industry product and cleanly handled research samples.	80

51. Inter-site variation in *P. ornatus* tail flesh concentration in 'clean' and 'industry' samples collected from southern Orman reefs in June 1992. 82