ENVIRONMENTAL MERCURY IN MARINE WATER AND FISH FROM KOSRAE STATE, FSM

by

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INTRODUCTION

The Water and Energy Research Institute (WERI), University of Guam, conducted a marine water quality monitoring program for the airport and dock facility construction project for Kosrae State, FSM. This monitoring program was initiated in May 1982 and completed in July 1984. Physical and chemical water quality parameters were measured in near-surface waters on a quarterly basis at 10 water quality stations within Okat harbor. Concentrations of the heavy metal mercury (Hg) were repeatedly measured in excess of the Trust Territory of the Pacific Islands (TTPI) marine water quality standard (0.10 µg/ℓ). These higher mercury concentrations appeared to be related to the construction project. Therefore, it was possible that fish in the vicinity of Okat harbor had higher than normal accumulations of mercury within their tissue. Since fish from the harbor area were being routinely harvested for food by local and construction personnel, it was deemed necessary to investigate mercury concentrations in food fish.

Mercury, in the form of methyl-mercury, can build-up in a food-chain by a process of bio-accumulation. This process will cause larger predatory fish to have higher mercury concentrations in muscle tissue. There is documentation which shows that mercury levels in fish can exceed by several orders of magnitude the levels of mercury found in marine water (Friberg and Vostal, 1972; Hartung and Dinman, 1972; McIntyre and Mills, 1978). Accumulation of mercury to toxic levels in food-chains occurs when the mercury source is persistent and the fish in the food-chain can not efficiently eliminate it from their systems. Practically all the mercury in fish of sizes normally eaten exists as methyl-mercury (McIntyre and Mills, 1978). There is a positive correlation between methyl-mercury content in the axial muscle and total weight and age of the fish (Friberg and Vostal, 1972). Mercury tends to accumulate with time within the fish, so that concentration relates to size. However, it is generally found that exposure time to mercury is more of an influential factor than age or weight. There is a background concentration of mercury in seawater from natural sources, which is generally in the form of chlorocomplexes (Friberg and Vostal, 1972). Mercury concentrations in seawater that was considered unpolluted were reported around 0.03 ppb (parts per billion) and at slightly higher levels (Friberg and Vostal, 1972; Officer and Ryther, 1981).

Since fish bio-accumulate mercury (methyl-mercury) in their muscle tissue, an analysis of fish muscle tissue can be made to determine if a mercury contamination problem exists. Excessive mercury levels in fish can indicate a chronic mercury source. A preliminary sampling project was conducted by WERI in October 1983 for mercury concentrations in bottom fish from Okat harbor (Clayshulte, 1984a). This study indicated a potential mercury contamination problem with higher than expected concentrations in medium-sized predatory fish. However, insufficient fish (both numbers and species) were assayed to clearly indicate either the seriousness or magnitude of the problem. Therefore, a more extensive fish sampling and mercury analyses program was proposed for Kosrae.

OBJECTIVE

A comprehensive monitoring program was conducted to assess the problem of mercury in the Kosrae nearshore marine environment. Determinations were made of mercury concentrations in marine waters from selected environments and for food fish taken from these waters. The project assayed different fish species with as large a size range as possible.

METHODS

A single trip was made to Kosrae for all environmental mercury sampling. At distinct locations along the coast of Kosrae (Figure 1), transient and non-transient fish were caught and subsequently analyzed for total mercury content. Fish and water collections were made in harbor and reef environments. The required fish were caught using whatever methods were appropriate for the different reef environments (i.e., hook and line, gill nets, spear gun). The Kosrae State Marine Resources Department provided field assistance in fish collections (both personnel and boats) and provided storage space for specimens. The Kosrae State Environmental Health Department provided field assistance in water collections.

Fish were collected from 2 harbor environments: Okat and Lelu (Figure 1). Okat harbor was a recently disturbed harbor environment with suspected mercury contamination (Figure 2), while Lelu harbor represented an environment already subjected to continued human impacts and a dock facility (Figure 3). A section of coastline near the village of Walung was selected as a control site for fish collections (Figure 1). Originally, Utwe and Taf harbors were selected as non-impacted control harbors (Figure 4), but rough sea conditions and excessive turbidity levels (from natural and man-induced processes) required a change of site. Water samples were collected from the Utwe and Taf harbors for mercury analyses (Figure 4). The Walung coastline was selected as the alternate control site for fish collection (Figure 1). The Walung coastline was considered pristine in relation to water quality, however, it was possible that transient fish from Okat could have migrated into Walung reef environments.

Fishing locations (Okat, Lelu and Walung) were subdivided into catch areas. Subareas in Okat harbor corresponded to water quality stations used in the airport and dock construction monitoring program (Figure 2). There were 14 areas designated for Okat harbor, however, fish were not collected from all areas. Lelu harbor was divided into 5 areas (Figure 3). Walung coastline fish collections were restricted to 5 locales which were classified as 3 areas (Figure 5). Most of the fish caught at Walung were from the primary area (Figure 5).

Each fish caught was given a unique identification number and placed in a separate collection bag. Catch records were kept for all collected fish specimens (Table 1). The catch record included identification numbers, sampling date and time, major location, specific catch area, depth, environment, fork length (centimeters, cm) and total weight (grams, g). Fish were collected from different types of reef environments and at varying depths within each of the 3 major locations. Reef environments were reef-flats, reef margins, shallow and deep patch reefs, fringing reefs

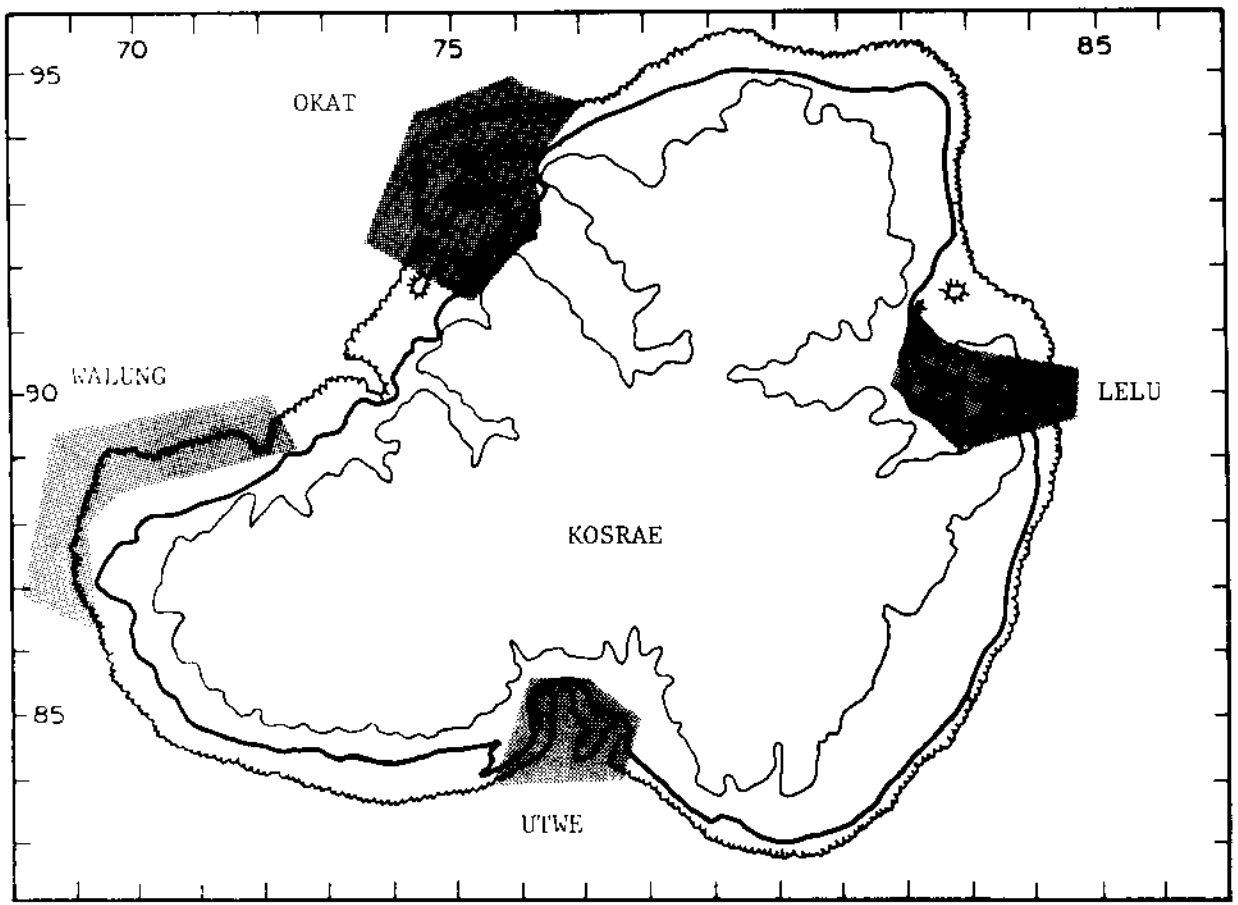

Figure 1. Kosrae Island with location of study areas.

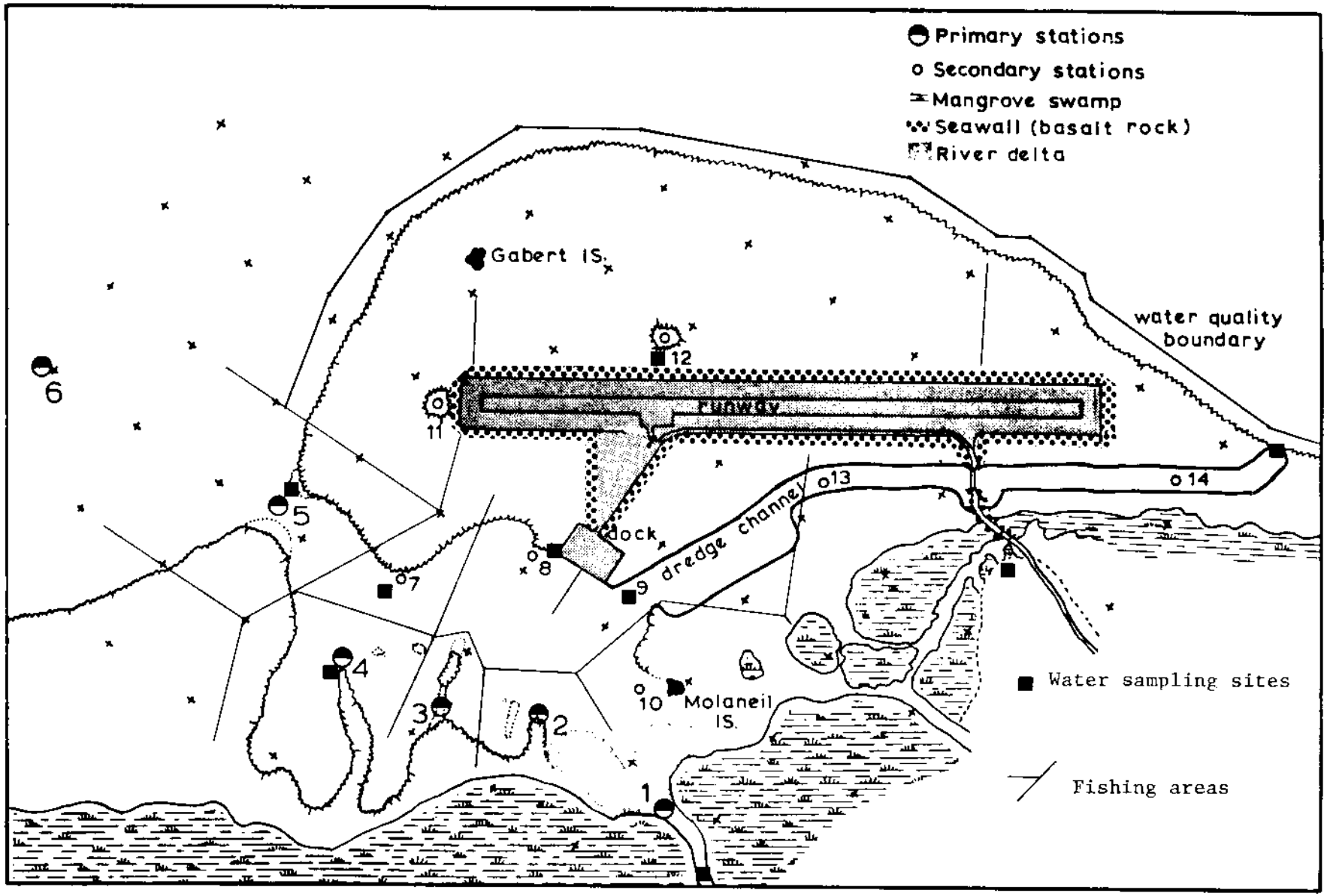

Figure 2. Okat Harbor with location of fish and water sampling areas. Fish sampling areas correspond with primary and secondary water quality stations.

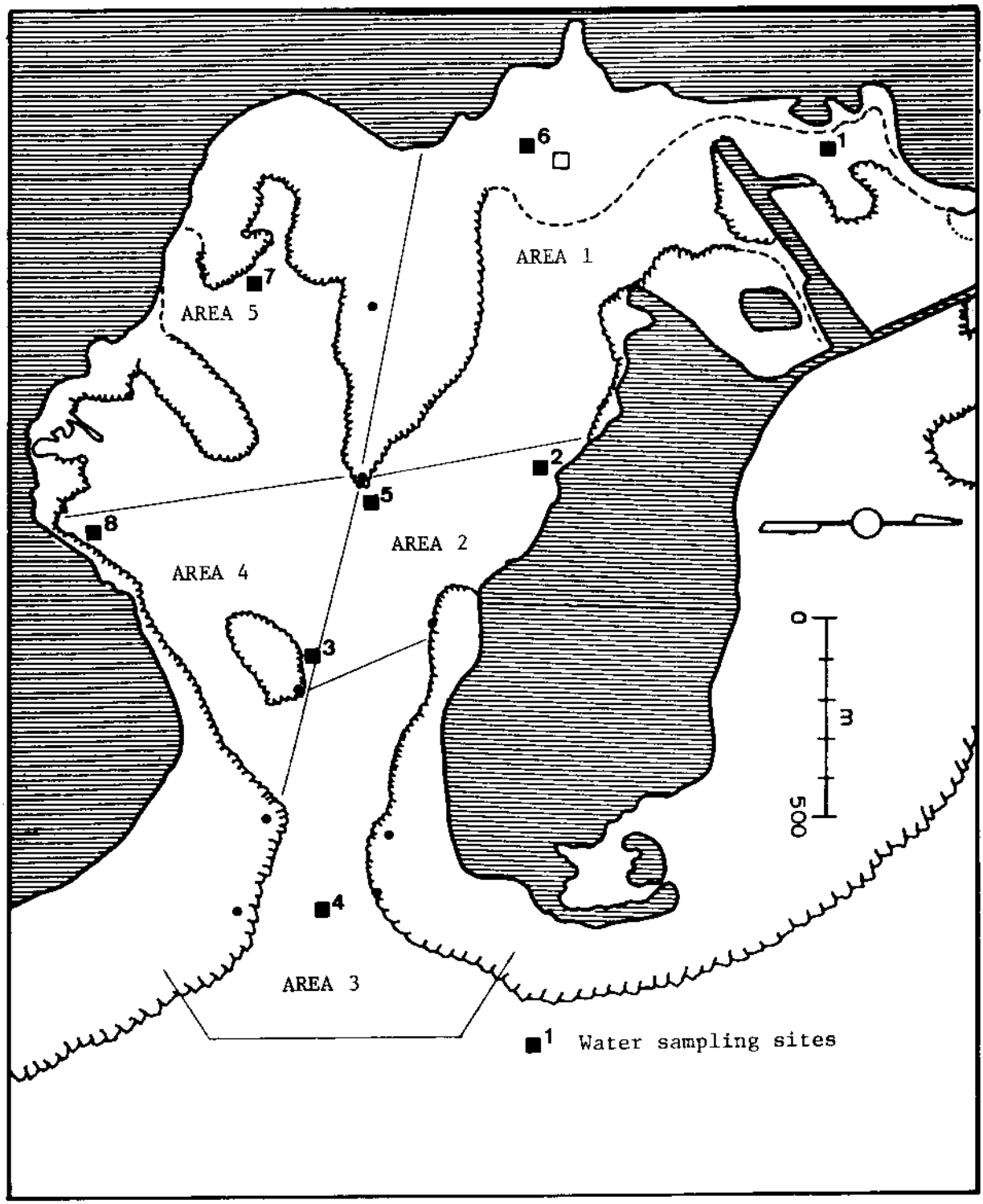

Figure 3. Lelu Harbor with location of fish and water sampling areas. Two water samples were taken from the Tofol stream; below the oxidation ponds, and above the Tofol dam.

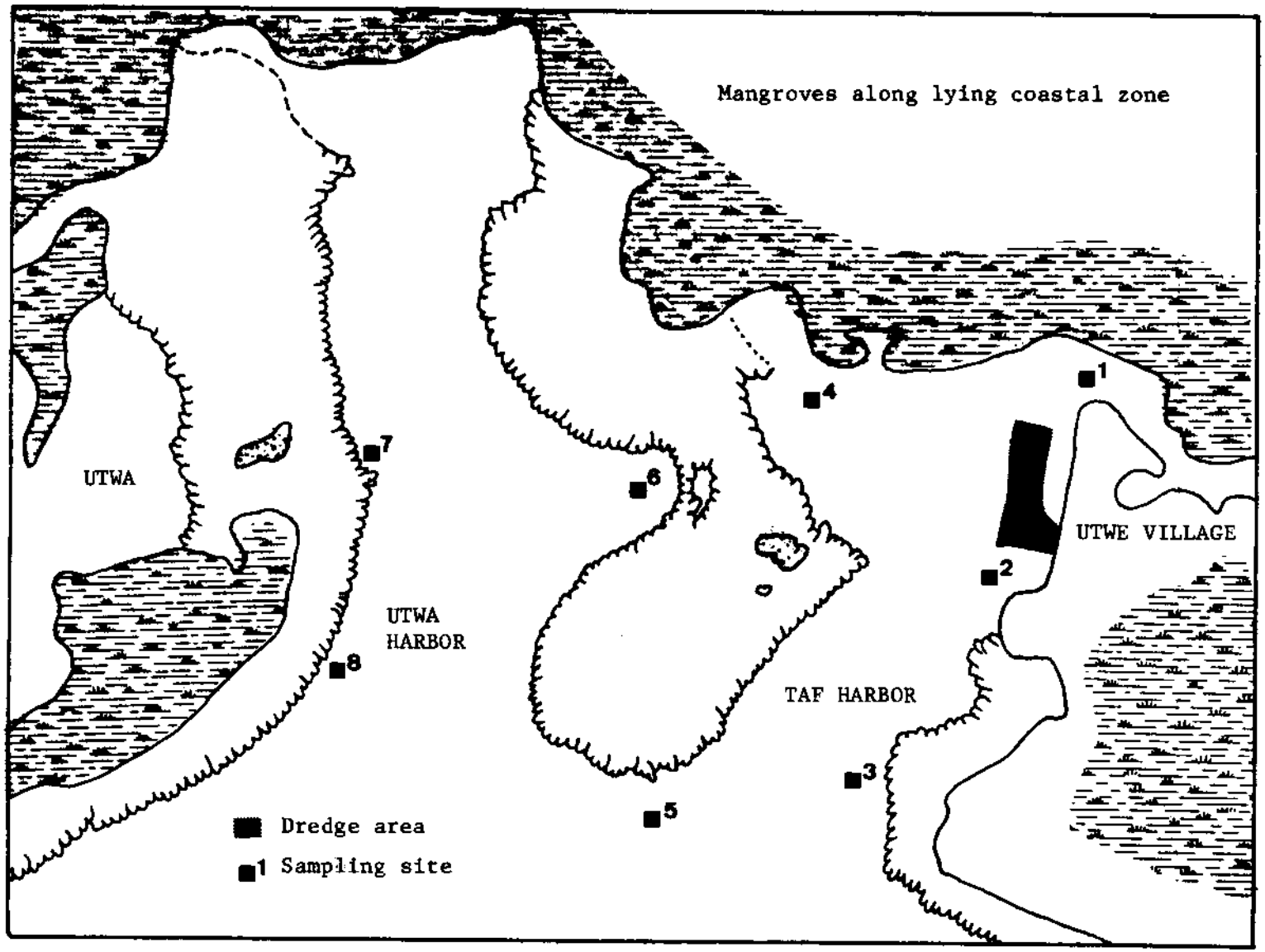

Figure 4. Utwe harbor with water sample sites.

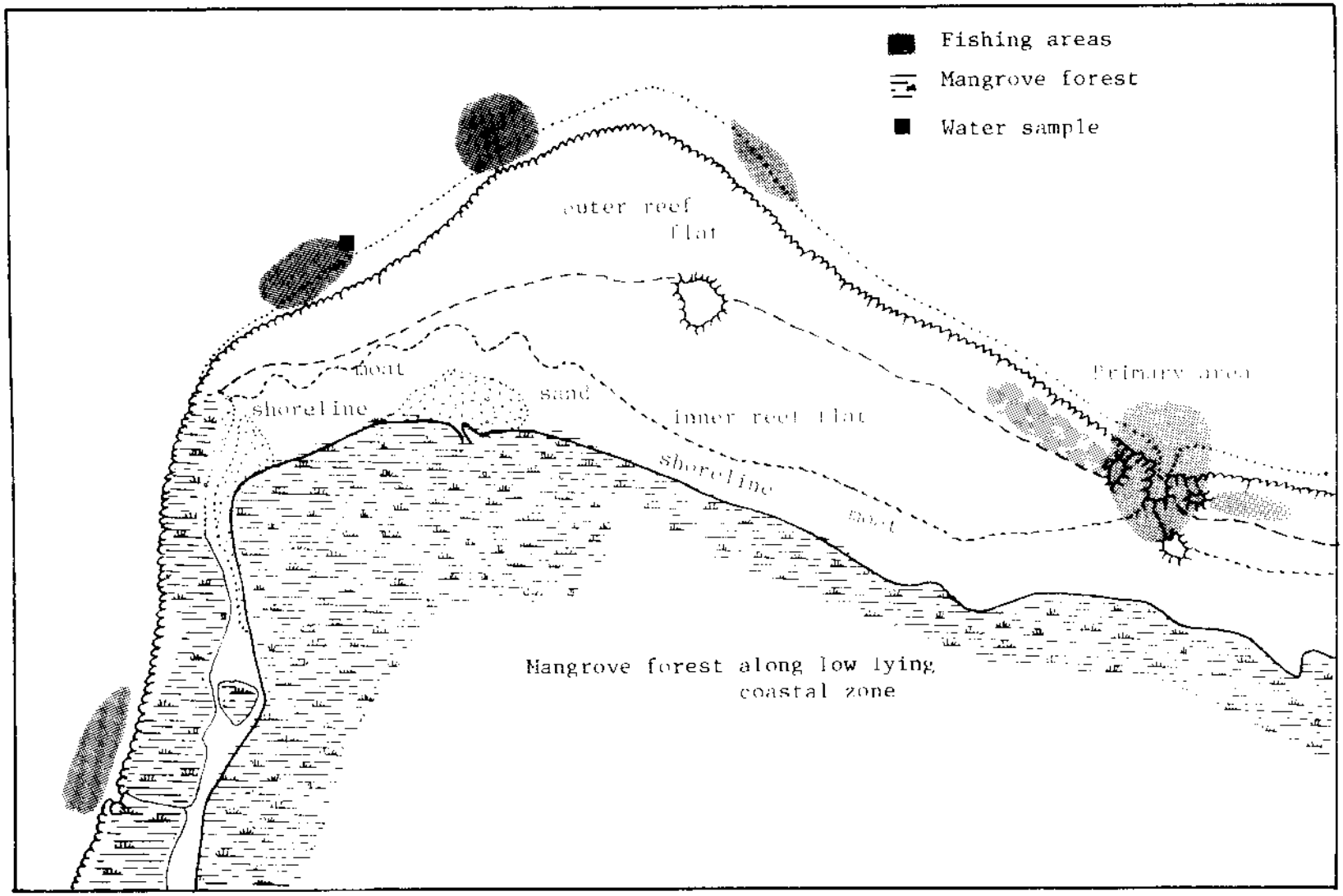

Figure 5. Walung coastline with fish collection areas.

Table 1. Fish catch record.

Sample	Date	Time	Location	Area	Environment	Depth (ft)	Fork Length (cm)	Total Weight (gm)
1	13-7-84	1020	Okat	3	Patch Reef	80-100	37	1590
2	13-7-84	1030	Okat	3	(scatter	80-100	21	250
3	13-7-84	1015	Okat	3	coral/mud)	80-100	19	188
4	13-7-84	1040	Okat	3		80-100	26	626
5	13-7-84	1100	Okat	3		80-100	23	452
6	13-7-84	1130	Okat	3		80-100	17	178
7a	13-7-84	1030	Okat	3		80-100	17	150
7b	13-7-84	1030	Okat	3		80-100	16	132
7c	13-7-84	1030	Okat	3		80-100	14	79
8	13-7-84	1345	Okat	9	edge reefflat	35	18	117
9	14-7-84	1410	Okat	4	Patch Reef	45-50	19	138
10	14-7-84	0830	Okat	4	(hard bottom)	80-100	22	290
11	14-7-84	1430	Okat	3		80	19	158
12	14-7-84	1100	Okat	2	Sand Flats	10	22	202
13	14-7-84	0945	Okat	4	Patch Reef	80-100	29	550
14	14-7-84	1410	Okat	4		45-50	15	91
15a	14-7-84	0700	Okat	4		80-100	18	125
15b	14-7-84	0700	Okat	4		80-100	17	132
15c	14-7-84	0700	Okat	4		80-100	16	118
16a	15-7-84	1300-1500	Okat	14	Reef Margin	0-1	25	366
16b	15-7-84	1300-1500	Okat	14	(shallow/	0-1	21	219
16c	15-7-84	1300-1500	Okat	14	extensive	0-1	19	146
17	15-7-84	1300-1500	Okat	14	coral)	0-1	24	362
18	15-7-84	1300-1500	Okat	14		0-1	16	136
19	15-7-84	1300-1500	Okat	14		0-1	25	330
20	17-7-84	0800	Okat	13	Reef Flat (mud)	exposes	30	428
22	17-7-84	0600	Lelu	1	Reef Flat	exposes	17	126
23	17-7-84	1015	Lelu	4	Patch Reef	50	20	167
24	18-7-84	1100	Lelu	2	Patch Reef	80	22	296

Table 1. continued

Sample	Date	Time	Location	Area	Environment	Depth (ft)	Fork Length (cm)	Total Weight (gm)
25	18-7-84	0930	Lelu	4	Reef Flat	exposes	24	442
26a	18-7-84	0830	Lelu	5	(Halimeda/	0-2	16	123
26b	18-7-84	1000	Lelu	5	Porities w/	0-2	15	100
27	18-7-84	1000	Lelu	5	sand)	0-2	12	63
28	18-7-84	1000	Lelu	5		0-2	17	109
30a	18-7-84	1200	Lelu	3	Fringing Reef	110-120	15	120
30b	18-7-84	1200	Lelu	3	(Harbor	110-120	15	110
30c	18-7-84	1200	Lelu	3	entrance)	110-120	13	74
30d	18-7-84	1200	Lelu	3		110-120	13	65
31	18-7-84	1600	Lelu	2	Harbor Floor	120	47	1360
32	18-7-84	1700	Lelu	5	(muddy bottom)	60	22	306
33	18-7-84	1700	Lelu	5		60	33	570
34a	19-7-84	0800	Lelu	3	Fringing Reef	100	16	107
34b	19-7-84	0900	Lelu	3	(rocky w/mud)	100	16	98
35a	19-7-84	0900-0930	Lelu	4	Fringing Reef	70	15	72
35b	19-7-84	0900-0930	Lelu	4	(rocky w/mud)	70	12	49
35c	19-7-84	0900-0930	Lelu	4		70	14	55
35d	19-7-84	0900-0930	Lelu	4		70	14	69
35e	19-7-84	0900-0930	Lelu	4		70	14	65
36a	19-7-84	0830	Lelu	1	Reef Flat	0-2	19	165
36b	19-7-84	0830	Lelu	1	(sandy)	0-2	18	120
37	19-7-84	0830	Lelu	1		0-2	8	58
38	19-7-84	1300	Lelu	2	Shallow, rocks	exposes	38	310
39	19-7-84	2100	Lelu	2	Fringing Reef	0-3	20	236
40	19-7-84	2000-2200	Lelu	1	Reef Flat	0-3	20	220
41	19-7-84	2000-2200	Lelu	1	(sand flats,	0-3	32	318
42	19-7-84	2000-2200	Lelu	1	few rocks,	0-3	23	412
43	19-7-84	2000-2200	Lelu	1	debris)	0-3	17	158
44	19-7-84	2000-2200	Lelu	1		0-3	18	98
45	20-7-84	0600-1200	Lelu	1	Reef Flat	exposes	26	169

Table 1. continued

Sample	Date	Time	Location	Area	Environment	Depth (ft)	Fork Length (cm)	Total Weight (gm)
46	20-7-84	0600-1200	Lelu	1	(sandy/	0-3	53	389
47a	20-7-84	0600-1200	Lelu	1	Halimeda)	0-3	30	247
47b	20-7-84	0600-1200	Lelu	1		0-3	25	184
48a	20-7-84	0600-1200	Lelu	4	Fringing Reef	95-110	16	109
48b	20-7-84	0600-1200	Lelu	4	(harbor	95-110	14	82
48c	20-7-84	0600-1200	Lelu	4	entrance)	95-110	12	64
48d	20-7-84	0600-1200	Lelu	4		95-110	14	83
48e	20-7-84	0600-1200	Lelu	4		95-110	16	139
49	20-7-84	1200-1530	Lelu	4	Fringing Reef	30	22	284
50	20-7-84	1200-1530	Lelu	4	(shallow,	30	16	110
51	20-7-84	1200-1530	Lelu	4	coral zone,	30	24	373
52	20-7-84	1200-1530	Lelu	4	inside harbor)	30	24	425
53	20-7-84	1200-1530	Lelu	4		25-30	19	158
54a	20-7-84	1200-1530	Lelu	4		25-30	18	125
54b	20-7-84	1200-1530	Lelu	4		25-30	17	106
54c	20-7-84	1200-1530	Lelu	4		30	17	103
55	20-7-84	1200-1530	Lelu	4		30	23	397
56	20-7-84	1200-1530	Lelu	4		25-30	16	101
57a	20-7-84	1200-1530	Lelu	4		25-30	18	171
57b	20-7-84	1200-1530	Lelu	4		25-30	15	85
58	20-7-84	1200-1530	Lelu	4		25-30	22	260
59a	20-7-84	1200-1530	Lelu	4		30	18	139
59b	20-7-84	1200-1530	Lelu	4		30	16	109
59c	20-7-84	1200-1530	Lelu	4	Fringing Reef	30	15	71
59d	20-7-84	1200-1530	Lelu	4	(shallow)	30	16	89
60	20-7-84	1200-1530	Lelu	4		30	15	95
61a	20-7-84	1200-1530	Lelu	4		30	16	84
61b	20-7-84	1200-1530	Lelu	4		30	18	101
62	20-7-84	1200-1530	Lelu	4		30	16	159
63	20-7-84	1200-1530	Lelu	4		30	18	70

Table 1. continued

Sample	Date	Time	Location	Area	Environment	Depth (ft)	Fork Length (cm)	Total Weight (gm)
64	20-7-84	1200-1530	Lelu	4		30	37	2000
65a	20-7-84	0700-0900	Lelu	5	Reef Flat	exposes	20	150
65b	20-7-84	0700-0900	Lelu	5	(sand)	0-2	18	118
66a	20-7-84	0700-0900	Lelu	5		0-2	16	84
66b	20-7-84	0700-0900	Lelu	5		0-2	15	64
66c	20-7-84	0700-0900	Lelu	5		0-2	14	58
67	20-7-84	0700-0900	Lelu	5		0-2	9	20
68	20-7-84	2000	Okat	14	Reef Flat	exposes	22	267
69	20-7-84	2000	Okat	14	(hard)	0-2	18	172
70	21-7-84	0800	Lelu	5	Reef Flat	exposes	22	340
71	21-7-84	0800	Lelu	5	(sandy)	0-2	19	172
72	21-7-84	0800	Lelu	5		0-2	12	64
73	22-7-84	1400-1700	Okat	10	Fringing Reef	15-30	22	248
74a	22-7-84	1400-1700	Okat	10	(entrance to	15-30	13	99
74b	22-7-84	1400-1700	Okat	10	channel,	15-30	11	52
75	22-7-84	1400-1700	Okat	10	rocky, edge)	20	21	250
76	22-7-84	1400-1700	Okat	10		20	20	209
77a	22-7-84	1400-1700	Okat	10		20	21	207
77b	22-7-84	1400-1700	Okat	10		20	12	61
78a	22-7-84	1400-1700	Okat	10		20	15	87
78b	22-7-84	1400-1700	Okat	10		20	14	83
78c	22-7-84	1400-1700	Okat	10		20	12	56
79a	22-7-84	1400-1700	Okat	10		15-30	20	185
79b	22-7-84	1400-1700	Okat	10		15-30	15	85
80a	22-7-84	1300-1400	Okat	14	Fringing Reef	30	13	69
80b	22-7-84	1300-1400	Okat	14	(channel, reef	30	12	52
80c	22-7-84	1300-1400	Okat	14	margin)	30	12	46
81	22-7-84	1400	Okat	14		30	20	200
82	22-7-84	1300-1400	Okat	14		30	21	238
83	22-7-84	0730-1130	Okat	13	Reef Flat	0-2	14	69

Table 1. continued

Sample	Date	Time	Location	Area	Environment	Depth (ft)	Fork Length (cm)	Total Weight (gm)
84	22-7-84	0730-1130	Okat	13	(muddy)	0-2	21	295
85	22-7-84	0730-1130	Okat	13		0-2	28	352
86	22-7-84	0830	Okat	3	Patch Reef	30	15	87
87	22-7-84	0830	Okat	3	(shallow)	30	23	298
88	22-7-84	0930	Okat	3	Patch Reef	30	19	150
89	22-7-84	0930	Okat	3		30	20	206
90a	22-7-84	1100	Okat	5	Fringing Reef	20	18	174
90b	22-7-84	1100	Okat	5	(edge)	20	16	99
91	22-7-84	1100	Okat	5		20	11	69
92	22-7-84	1100	Okat	14	Channel mouth	30	16	84
93	23-7-84	1100-1400	Walung	1	Fringing Reef	15-30	24	445
94	23-7-84	1100-1400	Walung	1	(margin zone	15-30	20	347
95	23-7-84	1100-1400	Walung	1	w/wide spur	15-30	21	390
96	23-7-84	1100-1400	Walung	1	and groove;	15-30	21	185
97a	23-7-84	1100-1400	Walung	1	very clear)	15-30	19	150
97b	23-7-84	1100-1400	Walung	1		15-30	16	116
98a	23-7-84	1100-1400	Walung	1		15-30	19	166
98b	23-7-84	1100-1400	Walung	1		15-30	14	89
99	23-7-84	1100-1400	Walung	1		15-30	21	248
100	23-7-84	1100-1400	Walung	1		15-30	13	97
101a	23-7-84	1100-1400	Walung	1		15-30	16	83
101b	23-7-84	1100-1400	Walung	1		15-30	15	66
102a	23-7-84	1200	Walung	3	Reef Flat	exposes	20	217
102b	23-7-84	1200	Walung	3	(outer, in	0-2	21	218
103	23-7-84	1200	Walung	3	surf zone	0-2	14	96
104	23-7-84	1200	Walung	3		0-2	12	80
105	23-7-84	1200	Walung	3		0-2	17	130
106a	24-7-84	0900	Walung	2	Reef margin	20	27	600
106b	24-7-84	0930	Walung	2	(w/drop off	40	22	259
107	24-7-84	0930	Walung	2	extensive	40	17	84

Table 1. continued

Sample	Date	Time	Location	Area	Environment	Depth (ft)	Fork Length (cm)	Total Weight (gm)
108a	24-7-84	1000	Walung	2	coral, deep	40	27	345
108b	24-7-84	1000	Walung	2	hole on reef	40	18	175
109	24-7-84	1100	Walung	2	margin)	60	18	232
110	24-7-84	1130	Walung	2		90	18	133
111a	24-7-84	1230	Walung	2		60	20	125
111b	24-7-84	1230	Walung	2		60	14	66
112	24-7-84	1400	Walung	2		30	36	444
113	24-7-84	1000-1300	Walung	3	Reef Flat	exposes	20	250
114a	24-7-84	1000-1300	Walung	3	(sand, coral)	0-3	21	325
114b	24-7-84	1000-1300	Walung	3		0-3	20	237
115a	24-7-84	1000-1300	Walung	3		0-3	16	108
115b	24-7-84	1000-1300	Walung	3		0-3	15	97
116	24-7-84	1000-1300	Walung	3		0-3	22	296
117	24-7-84	1000-1300	Walung	3		0-3	20	214
118	24-7-84	1000-1300	Walung	3		0-3	16	114
119	24-7-84	1000-1300	Walung	3	Reef Flat	exposes	17	111
120	24-7-84	1000-1300	Walung	3	(sandy, coral,	0-4	48	438
121	24-7-84	1000-1300	Walung	3	Halimeda)	0-4	10	45
122	24-7-84	1000-1300	Walung	3		0-4	15	170
123	24-7-84	1000-1300	Walung	3		0-4	30	578
124	24-7-84	1000-1300	Walung	3		0-4	26	506
125	24-7-84	1000-1300	Walung	3		0-4	11	55
126	24-7-84	1000-1300	Walung	3		0-4	12	92

along shallow portions of harbors (channels), and fringing reefs along deep portions of harbors. There were 4 depth zones used to classify catch depths: 0-20 ft (7-16m), 21-50 ft (16-33m), 51-100 ft, and >100 ft (33 m).

Fish specimens in the field were kept on ice. Specimens returned from the field were washed with rainwater and placed whole, if possible, in pre-cleaned 1 gallon zip-lock bags. Fish which were too large for the bags were filleted, with only the fillets being retained for analyses. These bagged specimens were placed in the local refrigeration plant for cold storage. Frozen fish and fillets were packed in ice chests for return to Guam. Fish samples were kept frozen in transit.

At each harbor (Okat, Lelu and Utwe), sufficient water samples were collected to characterize mercury levels in marine water at each site. Two water samples were collected from the Walung coastline. Major freshwater flows into Lelu and Okat harbors were sampled for mercury analyses. Water samples were collected by a PVC water sampling bottle (2.2ℓ capacity). One liter (ℓ) of the sample was filtered through an acid cleaned distilled-deionized water-rinsed 0.45μ membrane filter and preserved (2 mℓ HNO_3 ultrex grade) for dissolved mercury determination. An unfiltered sample of water was also preserved for total mercury determination. At Okat, a second set of water samples was collected at monitoring stations and preserved for analyses of other heavy metals: arsenic, cadmium, chromium, copper, nickel, lead and zinc. Total and dissolved mercury samples were analyzed by cold vapor atomic absorption. The analytical methodology for other metals were analyzed according to United States Environmental Protection Agency (US EPA) methods of analyses (US EPA, 1979) and Standard Methods for the Examination of Water and Waste Waters (Standard Methods, 1980).

Fish muscle tissue was used exclusively in the mercury testing. At the WERI laboratory, a strip of at least 40 g or a whole fillet was removed from below the first dorsal fin. This strip was subsectioned into two subsamples for replicate analyses. The flesh was placed into pre-cleaned zip-lock bags, refrozen, and stored for later analyses. The whole fillets or smaller sections of fillets were partially thawed and a 2 to 5 g portion was removed with a stainless steel scalpel. Generally, the flesh removed was all muscle tissue. Although in a minority of cases, where available samples were small, it was unavoidable to exclude all traces of membrane, scale, and blooded tissue.

The fish tissue was analyzed (wet weight) by the nitric acid-vanadium oxide digestion procedure and the total mercury was analyzed by hydride generation with atomic absorption on a Perkin Elmer MHS-10 system. The digestion procedure was a modified method adapted from Horwitz (1980), Dave et al. (1981), and Knechtel and Fraser (1979). Fish sections were placed into specially cleaned 300 mℓ BOD bottles which contained 20 mℓ of 50% nitric acid (Mercury ultrex grade or trace metal grade HNO_3), and 20 mg ± 5 mg vanadium oxide (V_2O_5) catalyst. These bottles were sealed with an aluminum foil cap and placed in a 95°C covered water bath for 1 to 2 hours. At completion of the digestion period, the digestate was a clear pale yellow to yellow-green mixture. To remove fat globules, if any, samples

were filtered through acid washed and pre-rinsed Whatman #2 filter paper. Samples were diluted to a final volume of 50 mℓ with distilled deionized water.

One to 2 mℓ aliquots were taken from the diluted digestate and used in the cold vapor atomic absorption spectrophotometeric method. The MHS-10 system was used with sodium borohydride to reduce mercury in the digestate to mercury vapor. The mercury vapor was swept along by hydrogen (H_2) gas produced from the reaction of borohydride reagent (3% in 1% sodium hydroxide) with the dilute acid (1.5% HNO_3) and residual hydrogen ions in the digestate. The mercury vapor and H_2 gases flowed into a quartz absorbance tube which had a focused light beam from a mercury hollow cathode light source. Argon gas was used to purge the system of residual mercury vapors between samples. The volume in the reactor vessel of the MHS-10 was maintained at 10 mℓ by making up the 1 or 2 mℓ sample digestate aliquot to 10 mℓ with 1.5% HNO_3. Prior to attaching the reactor tube 5% w/w, $KMNO_4$ (mercury analysis grade) was added until a permanent faint permanganate color appeared. This was done to oxidize any remaining unoxidized dissolved organics or nitrous compounds.

Blanks consisting of digestion solution without any added fish tissue and methyl-mercury standards (CH_3HgCl) were carried through the digestion procedure on a daily basis. Blank absorbance and background absorbance readings were used to correct sample absorbances. Actual calibration of the digestion procedure utilized methyl-mercury labeled fish samples. The aqueous methyl-mercury standards were used to monitor digestion efficiency. A fish sample was obtained from the U.S. Environmental Protection Agency (sample no. 1, serial number 0465) which had a known concentration of methyl-mercury (2.52 ppm, with 1.20 to 3.80 ppm - 95% confidence limits). The sample was assayed with the method outlined above and the mercury concentration was determined to be 2.87 ppm.

The MHS-10 system was designed primarily for water analyzes. Digestates comprised of organics and salts caused some problems with the system. A major problem was due to foaming action produced after the additions of the borohydride reagent. Although a 10 to 50 mℓ aliquot of sample could be analyzed in the MHS-10 system, severe foaming interfered with access flow of mercury vapor to the absorbance cell. This interference produced smaller peak absorbances, and rarely, mutliple peaks or inconsistently shaped peaks on the recorded output. In order to minimize this problem, smaller aliquots (1 to 2 mℓ) were used for most mercury analyses. There was also a minor problem with water droplet carry-over caused by bursting foam bubbles in the tubing carrying the mercury vapor to the absorbance cell. This was a time related factor which produced an increasing baseline noise level and caused some mercury carry-over problems. The tubing was intermittently rinsed with ethanol, dried and recalibrated. Frequent checks of both blanks and standards were necessary to monitor foam related problems.

RESULTS AND DISCUSSION

Fish

There were a 172 fish specimens collected from Okat, Lelu and Walung marine waters for mercury analysis of axial muscle tissue. There were 72 fish species belonging to 24 Families caught in these locations (Table 2). Since it was difficult to collect the same fish species from all 3 locations, an attempt was made to obtain the maximum number of species and size ranges from each location. There were 9 fish Families that had species common to all 3 locations (Table 2). The major Families, which included food fish, caught in this project were Serranidae (grouper; 6 species) Carangidae (jacks; 9 species), Lujanidae (snappers, 7 species), Lethrinidae (commonly referred to as snappers in the past and more recently emperors; 5 species), Mullidae (goat fish; 5 species), Labridae (wrasses; 7 species), Scaridae (parrot fish; 4 species), Acanthuridae (surgeon fish; 6 species), Siganidae (rabbit fish; 3 species) and Balistidae (trigger fish; 4 species). The remaining Families had only 1 or 2 species represented from the 3 locations.

In order to maximize catch diversity and size, collections were made in different reef environments at various depths. Fishing efforts were made in the following reef environments: reef-flats, fringing reefs and tops of large patch reefs which exposed at low tides; shallow and deep patch reefs from margins to lagoon or harbor floor; reef margins, exposed to open oceanic water; fringing reefs within shallow portions of harbor; fringing reefs within deeper portions of harbors; and channels, both man-made and natural. Although the catch depths were recorded for each fish specimen (Table 1), for analyses purposes only 3 depth zones were used: 0-20 feet (0-7m); 21-50 feet (7-16m); >50 feet (16m). An attempt was made to catch fish from all designated areas at the 3 locations, however, there were areas where fishing was unsuccessful. At least 4 fish specimens were caught within each of the following areas: Okat, areas 3, 4, 10, 14 (Figure 2); Lelu, areas 1, 3, 4, 5 (Figure 3); Walung, areas 1, 2, 3 (Figure 5).

In order to ascertain if mercury concentrations in fish from various reef environments were related to different functional groups, fish were categorized by trophic (food), habitat, aggregation and movement groups (Table 3). Trophic groups describe major food sources for different fish species. Since bio-accumulation is an important food-chain pathway to increase mercury, fish species which eat other fish and invertebrates would potentially have higher mercury concentrations. Habitat groups describe areas where fish species are likely to reside and feed. Fish species are found in schools, small groups, pairs or solitary aggregation groups. Fish species show different movement behaviors within nearshore and lagoon reef environments. These movement groups include wide-range movers, limited-range species, sedentary and territorial fish species. All of these functional groups can have an affect on mercury accumulation in different fish species, particularly when the mercury originates from a single source and is not wide spread within the marine environment.

Axial muscle tissues from 114 fish were analyzed for mercury concentration: Okat, 44 specimens from 20 genera; Lelu, 45 specimens from

Table 2. Taxa of fish sampled from 3 Kosrae locations. Sample numbers of fish are listed under catch location.

SPECIES	FISH SAMPLES BY LOCATION OKAT	LELU	WALUNG
Sphyrnidae			
Sphyrna sp.		31	
Clupeidae			
Sardinella sp.		67	
Muraenidae			
Sideria picta		38	
Synodontidae			
Saurida sp.		63	
Belonidae			
Strongylura incisa			120
Tylosurus crocodilis		46	
Holocentridae			
Sargocentron spinifer	2,10	39	
S. violaceus			109
Serranidae			
Cephalophalis analis	7,14,15	30,34,35,48,57	110
C. miniatus	6,79		
C. sexmaculatus	4, 5,13	24	
Epinephelus microdon	1		
E. hexagonatus	90		117
E. merra	9	59	
Carangidae			
Alectis ciliaris	82	33	
Carangoides ferdau		44	105
C. fulvoguttatus		32	96
C. orthogrammus	81		
C. sp.			123
Caranx melampygus	19	42	
C. sexfaciatus	12		
Scamberoides lysan		45	
Selar crumenophthalmus		66	

Table 2. continued.

SPECIES	FISH SAMPLES BY LOCATION OKAT	LELU	WALUNG
Leiognathidae			
Leiognathus sp. *equulus*		43,72	
Lutjanidae			
Aphareus furcatus			118
Lutjanus bohar			98
L. fulvus	68,73,74,86		
L. gibbus	77,78	60	
L. kasmira	80		107
L. monostigmus	8	40	
L. semicinctus	17		
Nemipteridae			
Scolopsis cancellatus			115
Gerreidae			
Gerres argyreus		36	
Lethrinidae			
Lethrinus cf. *semicinctus*			102
L. harak	18,75	55	106a
L. ornatus	76	49,50,51	106a
L. xanthochilus		52,53,54	
L. ramak		56	106b
Mullidae			
Mulloides flavolineatus		65	119
Parupeneus atrocingulatus	11	61	97,111
P. barberinus		28	
P. indicus		70	
Upeneus vittatus	85	71	
Chaetodontidae			
Chaetodon auriga			125
Pomacentridae			
Abudefduf sexfasciatus			100

Table 2. continued.

SPECIES	FISH SAMPLES BY LOCATION OKAT	LELU	WALUNG
Mugilidae			
Crenimugil crenilabis	20,84		
Sphyraenidae			
Sphyraena genie		41	
Labridae			
Cheilio inermis		47	
Cheilinus digrammus	3,88	23,58	
C. fasciatus	87		
C. unifasciatus			99
Novaculichtys taeniourus	92		
Thalassoma lutescens			101
T. purpureum	16		
Scaridae			
Scarus ghobban			112
S. globiceps			114a
S. niger			124
S. psittacus		26	114b
Acanthuridae			
Acanthurus triostegus			104,121
A. glaucoparieus			126
A. nigricaudus		37	
Naso unicornis			103,113
N. vlamingi			93
Ctenocheatus striatus		27	122
Siganidae			
Siganus argenteus		25	
S. punctatus			116
S. vermiculatus	68	22	
Bothidae			
Bothus pantherhinus	83		

Table 2. continued.

SPECIES	FISH SAMPLES BY LOCATION OKAT	LELU	WALUNG
Balistidae			
Balistapus undulatus	91	62	94
Melichthys vidua			95
Odonus niger	89		
Pseudobalistes flavimarginatus		64	

Table 3. Trophic, habitat, aggregation and movement groups of fish analyzed for mercury concentration. The key to the table is as follows:

I. Trophic Groups	II. Habital Groups	III. Aggregation Groups	IV. Movement Groups
P = planktivore	P = pelagic (open ocean)	S = schooler (practically always)	W = wide-range movers
I = invertebrate eater	C = coastal (open ocean)	A = aggregator (intermittantly forms small groups)	L = limited-range movers
F = fish eater	B = bays, mangrove areas	N = nonaggregator (often solitary or pairs)	S = sedentary (more or less)
B = browser	S = Surface		T = territorial
G = grazer	M = midwater		
O = omnivore	A = above bottom		
J = juvenial	D = demersal		
A = adult			

Species	Trophic Group	Habitat Group	Agrregation Group	Movement Group
Sphyrna sp.	I - IF	II - CSMA	III - j=S, a = N	IV - W
Sardinella sp.	I - P	II - PCBS	III - S	IV - W
S. picta	I - F	II - CD	III - N	IV - S
Saurida sp.	I - F	II - CBD	III - N	IV - S
S. incisa	I - F	II - PCBS	III - S	IV - W
T. crocodilis	I - F	II - PCBS	III - NA	IV - W
S. spiniler	I - IF	II - CDA	III - N	IV - L
S. violaceus	I - IF	II - CDA	III - NA	IV - L
C. analis	I - IF	II - CD	III - N	IV - S
C. miniatus	I - FI	II - CD	III - N	IV - S
C. sexmaculatu	I - FI	II - CD	III - N	IV - S
E. microdon	I - IF	II - CD	III - N	IV - S
E. hexagonatus	I - FI	II - CD	III - N	IV - S
E. merra	I - FI	II - CD	III - N	IV - S
A. ciliaris	I - FP	II - CBMA	III - NA	IV - W
C. ferdau	I - FI	II - PCMA	III - j=S, a-AN	IV - W

Table 3. continued.

Species	Trophic Group	Habitat Group	Agrregation Group	Movement Group
C. fulvoguttatus	I - FI	II - j=BA, a=CMA	III - j=S, a=AN	IV - W
C. orthogrammus	I - FI	II - CBMA	III - AN	IV - W
C. melompygus	I - FI	II - CBMA	III - j=S, a=NA	IV - W
C. sexfasciatus	I - FI	II - CBMA	III - j=S, a=AN	IV - W
S. lysan	I - FI	II - CBMA	III - S	IV - W
S. crumenopthalmus	I - PIF	II - PCBSM	III - S	IV - W
L. equuluas	I - IF	II - CBA	III - S	IV - W
A. furcatus	I - FI	II - CM	III - AN	IV - W
L. bohar	I - FI	II - CM	III - NA	IV - W
L. fulvus	I - IF	II - CA	III - S	IV - W
L. gibbus	I - IF	II - j=BA, a=CA	III - S	IV - W
L. kasmira	I - IF	II - j=BCMA, a=CMA	III - S	IV - W
L. monostigmus	I - FI	II - j=CA, a=CDA	III - S	IV - W
L. semicinctus	I - FI	II - CA	III - S	IV - W
S. cancellatus	I - IF	II - CBA	III - AN	IV - W
G. orgyreus	I - I	II - CBA	III - AN	IV - W
L. semicinctus	I - IF	II - CBA	III - AN	IV - W
L. ramak	I - IF	II - CBA	III - AN	IV - W
L. harak	I - IF	II - CBA	III - AN	IV - W
L. ornatus	I - IF	II - CBA	III - A	IV - W
L. xanthochilus	I - IF	II - CA	III - AN	IV - W
M. flavolineatus	I - I	II - CBA	III - S	IV - W
P. atrocingulatus	I - I	II - CBA	III - S	IV - W
P. barberinus	I - I	II - CBA	III - AN	IV - W
P. indicus	I - I	II - CBA	III - NA	IV - W
U. vittatus	I - I	II - CBA	III - S	IV - W
A. sexfasciatus	I - PB	II - CBD	III - AN	IV - T
C. crenilabis	I - O	II - CBA	III - S	IV - W
S. genie	I - F	II - j-CM, a=PCM	III - j=S, a-NA;	IV - W
C. dinermis	I - FI	II - CA	III - N	IV - W
C. digrammus	I - FI	II - CA	III - N	IV - W
C. fasciatus	I - FI	II - CA	III - N	IV - W
C. unifasciatus	I - FI	II - CA	III - N	IV - W
N. taeniourus	I - I	II - CBD	III - N	IV - L

Table 3. continued.

Species	Trophic Group	Habitat Group	Agrregation Group	Movement Group
T. lutescens	I - j=O, a=IP	II - CA	III - AN	IV - L
T. purpureum	I - IP	II - CA	III - AN	IV - L
S. ghobban	I - G	II - CAD	III - A	IV - W
S. globiceps	I - G	II - CAD	III - A	IV - W
S. nigev	I - G	II - CAD	III - A	IV - W
S. psittacus	I - G	II - CAD	III - A	IV - W
A. triostegus	I - B	II - CA	III - S	IV - W
A. glaucoparieus	I - C	II - CA	III - S	IV - W
A. nigricaudus	I - G	II - CA	III - S	IV - W
N. unicornis	I - B	II - CAM	III - AN	IV - W
C. Striatus	I - G	II - CA		
S. argenteus	I - B	II - CBA	III - AN	IV - W
S. punctatus	I - B	II - CA	III - j=A, a=N	IV - W
S. vermiculatus	I - B	II - CBA	III - S	IV - W
B. pantherhinus	I - IF	II - D	III - N	IV - L
B. undulatus	I - O	II - CBD	III - N	IV - T
M. vidua	I - O	II - CAD	III - N	IV - L
O. niger	I - PO	II - CMD	III - S	IV - L
P. flavimarginatus	I - O	II - CAD	III - N	IV - L
C. auriga	I - O	II - CA	III - NA	IV - L

Table 4. Concentration of mercury in fish tissue.

Location	Sample no.	Genera	Hg Conc (ppm)
OKAT	1	Epinephelus	0.07
	2	Sargocentron	0.04
	3	Cheilinus	0.13
	4	Cephalophalis	0.05
	5	Cephalophalis	0.05
	6	Cephalophalis	0.05
	7a	Cephalophalis	0.04
	7b	Cephalophalis	0.24
	7c	Cephalophalis	0.25
	8	Lutjanus	<0.02
	9	Epinephelus	<0.02
	10	Sargocentron	0.07
	11	Parupeneus	<0.02
	12	Caranx	0.04
	13	Cephalophalis	0.32
	14	Cephalophalis	0.07
	15a	Cephalophalis	<0.02
	15b	Cephalophalis	<0.02
	15c	Cephalophalis	<0.02
	16a	Thalossome	<0.02
	16b	Thalossome	<0.02
	16c	Thalossome	0.29
	18	Aphareus	0.09
	19	Caranx	0.16
	68	Signaus	<0.02
	73	Lutjanus	<0.02
	75	Lethrinus	<0.02
	76	Lethrinus	<0.02
	77b	Lutjanus	0.02
	78a	Lutjanus	0.02
	78b	Lutjanus	<0.02
	80a	Lutjanus	<0.02
	80b	Lutjanus	<0.02
	81	Carangoides	0.05
	82	Alectus	0.06
	83	Bothus	0.11
	84	Crenimugil	<0.02
	85	Upeneus	0.23
	87	Cheilinus	0.28
	88	Cheilinus	0.03
	89	Idonus	0.04
	90a	Epinephelus	<0.02
	90b	Epinephelus	0.29
	91	Balistapus	0.04
	92	Novaculicthys	<0.02

Table 4. continued.

Location	Sample no.	Genera	Hg Conc (ppm)
LELU	22	Siganus	<0.02
	23	Cheilinus	<0.02
	24	Cephalophalis	0.05
	25	Siganus	<0.02
	30a	Cephalophalis	<0.02
	30c	Cephalophalis	<0.02
	31	Sphyrna	0.12
	32	Carangoides	0.11
	33	Alectis	<0.02
	34	Cephalophalis	<0.02
	35a	Cephalophalis	<0.02
	35b	Cephalophalis	0.25
	35c	Cephalophalis	<0.02
	35d	Cephalophalis	0.11
	35e	Cephalophalis	0.03
	36a	Gerres	<0.02
	38	Sideria	<0.02
	39	Sargocentron	0.08
	40	Lutjanus	<0.02
	41	Sphyraena	0.04
	43	Leiognathus	<0.02
	44	Carangoides	0.04
	46	Tylosurus	0.02
	47a	Cheilio	<0.02
	47b	Cheilio	<0.02
	49	Lethrinus	<0.02
	50	Lethrinus	0.16
	51	Lethrinus	<0.02
	52	Lethrinus	0.16
	53	Lethrinus	0.17
	55	Lethrinus	0.14
	57a	Cephalophalis	0.12
	57b	Cephalophalis	0.05
	59a	Epinephelus	<0.02
	59b	Epinephelus	<0.02
	59c	Epinephelus	<0.02
	59d	Epinephelus	<0.02
	60	Lutjanus	0.17
	61a	Parupeneus	0.05
	61b	Parupeneus	<0.02
	65a	Mulloides	0.04
	66a	Selar	<0.02
	70	Parupeneus	0.02
	71	Upeneus	0.05
	72	Leiognathus	0.02

Table 4. continued.

Location	Sample no.	Genera	Hg Conc (ppm)
WALUNG	95	Melichthys	<0.02
	96	Carangoides	<0.02
	97a	Parupeneus	0.15
	98a	Lutjanus	0.13
	99	Cheilinus	<0.02
	100	Abudefdul	<0.02
	102a	Lethrinus	<0.02
	102b	Lethrinus	<0.02
	105	Carangoides	<0.02
	107	Lutjanus	0.05
	108	Lutjanus	0.21
	110	Cephalophalis	<0.02
	112	Scarus	<0.02
	113	Naso	<0.02
	114a	Scarus	<0.02
	114b	Scarus	<0.02
	115b	Scolopsis	<0.02
	116	Siganus	<0.02
	117	Epinephalus	0.04
	119	Mulloides	0.08
	120	Strongylura	0.11
	121	Acanthurus	<0.02
	123	Carangoides	<0.02
	124	Scarus	<0.02
	126	Acanthurus	<0.02

20 genera; and Walung, 25 fish from 16 genera (Table 4). Mercury concentrations in excess of the lower detection limit (<0.02 ppm, wet weight) were found in 46.5% of the total assayed fish (Table 4). There were more fish in Okat (59%) that had detectable mercury concentrations compared with Lelu (44.5%) and Walung (28%). Highest concentrations of mercury in fish were from Okat and ranged from 0.28 to 0.32 ppm (wet weight). The highest mercury concentration in fish from Lelu was 0.25 ppm (wet weight) and Walung had a high of 0.21 ppm (wet weight).

There were no fish analyzed that had mercury concentrations in axial muscle which exceeded the United States Federal Food and Drug Administration (FDA) standard of 1.0 ppm (Figure 6). The Japanese have established a mercury regulation with a permissable methyl-mercury concentration in fish muscle tissue at 0.3 ppm (µg/kg) as wet weight. This regulation exempts all species of tunas and billfishes from this lower mercury level. The Swedish commission on Evaluating the Toxicity of Fish and the World Health Organization have established 0.03 mg/person/day as the safe ingestion level of methyl-mercury. This standard was established for methyl-mercury as opposed to total mercury, since practically all mercury in fish muscle tissue is in the form of methyl-mercury (Friberg and Vostal, 1972; Hartung and Dinman, 1972; McIntyre and Mills, 1978). The FDA standard was established for total mercury concentration at 1.0 ppm (µg/kg) as wet weight, based on a daily consumption rate of 30 g (0.066 pounds or 1.1 ounces) per person per day. Fish consumption rates in Kosrae are higher than this United States average rate of 30 g/day. A person that consumes about 225 g (½ pound or 8 ounces) of fish per day would require that fish to have a mercury concentration of less than 0.13 ppm for safe ingestion level (Figure 6). Based on a yearly consumption rate, it could be assumed that there would be a lower average consumption rate. Therefore, a more realistic, but still conservative, estimate of consumption rate in Kosrae would be about 3 times the United States rate or 90 g/person/day. At this consumption rate, the mercury standard for fish would be about 0.33 ppm as wet weight (Figure 6). Even based on this adjusted standard, there was no major health rish from eating fish caught in Okat harbor or elsewhere around Kosrae.

There were 18 fish samples, six from each location, sent to an independent laboratory (Huffman Laboratories, Inc.) for analysis of mercury in axial muscle (Table 5). The tissue sample (fillet) was split in half with one part sent to the laboratory for analysis and the other half retained for analysis at WERI (Table 5). Huffman Laboratory ran only a single mercury analysis for each tissue sample. The analysis method used by Huffman Laboratory was basically the same as used by WERI. The mercury was measured at Huffman Laboratory by flameless atomic absorption using a Varian AA 1275 with a Model 65 vapor generator accessory. The WERI analysis results on these split fish tissue samples represent the average of 2 to 4 separate analysis. The variance between the WERI analyses for a tissue sample was less than 5% with many of the samples showing no difference. There was no difference in analyzed mercury concentrations between Huffman and WERI laboratories for fish specimens from Walung. These fish were all below detection limit (<0.02 ppm). There were differences between laboratories for fish specimens from Okat and Lelu locations. For Okat fish, WERI mercury analyses showed 5 specimens with higher mercury concentrations when compared with Huffman Laboratory results. Four of these fish species had low mercury levels, as measured by

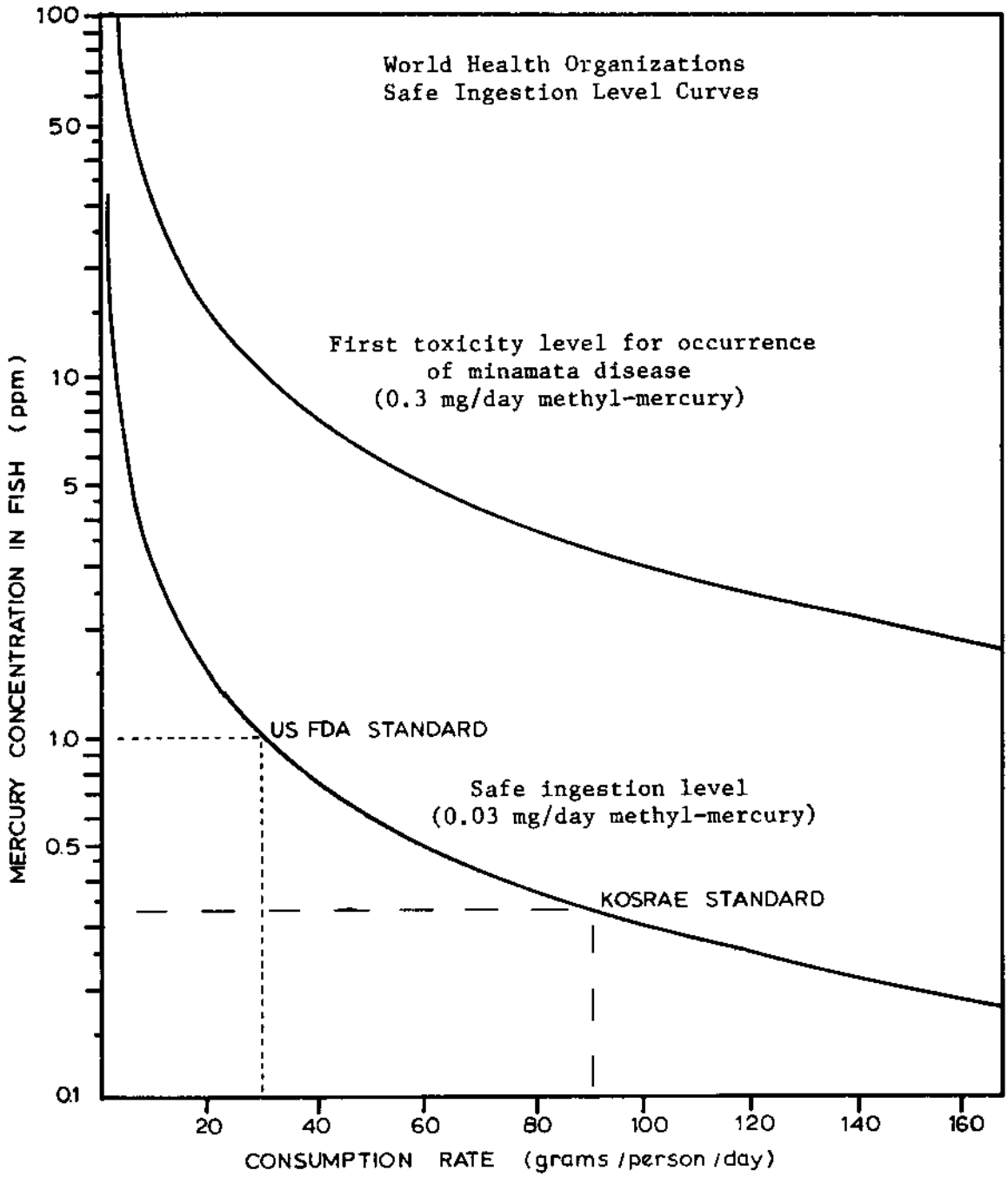

Figure 6. Safe and toxic levels of methyl-mercury in relation to consumption rate. The Kosrae standard is an estimate of the safe ingestion level for people who consumes 3 times the United States rate of fish.

Table 5. Concentration of mercury in fish tissue analyzed at Huffman Laboratory, Inc. A comparison is made between Huffman and WERI mercury analyses for a split fish tissue sample.

Location	Sample no.	Genera	Huffman Lab Hg Conc (ppm)	WERI Lab Hg Conc (ppm)
OKAT	1	Epinephelus	<0.02	0.07
	4	Cephalophalis	<0.02	0.05
	7a	Cephalophalis	<0.02	0.04
	76	Lethrinus	<0.02	<0.02
	85	Upeneus	<0.02	0.23
	88	Cheilinus	<0.02	0.03
LELU	23	Cheilinus	0.09	<0.02
	41	Sphyraena	<0.02	0.04
	49	Lethrinus	<0.02	<0.02
	52	Lethrinus	<0.02	0.04
	57a	Cephalophalis	<0.02	0.12
	71	Upeneus	<0.02	0.05
WALUNG	99	Cheilinus	<0.02	<0.02
	106b	Lethrinus	<0.02	<0.02
	110	Cephalophalis	<0.02	<0.02
	112	Scarus	<0.02	<0.02
	116	Siganus	<0.02	<0.02
	123	Carangoides	<0.02	<0.02

WERI, and could be considered consistent with the Huffman Laboratory results. There was a goat fish (Upeneus) which was measured by WERI mercury analysis as having a higher mercury concentration and was not comparable to the Huffman Laboratory result (Table 5). For Lelu fish, WERI mercury analysis had 4 fish specimens with slightly higher, but comparable, mercury concentrations when compared to the Huffman Laboratory results. There was a wrasse (Cheilinus) which Huffman Laboratory measured at a higher mercury concentration when compared to the WERI result. The precision of either the WERI or Huffman Laboratory tests for mercury of the split tissue samples was about 10 percent relative to a given value. It was ascertained that the WERI mercury analysis procedure provided a reasonably accurate assessment of mercury concentrations in fish.

Mean mercury concentrations in fish axial muscle were classified by location (Table 6). The mean mercury concentration in fish from Okat was 0.09 ppm (N=44); from Lelu it was 0.04 ppm (N=45); and from Walung it was 0.03 ppm (N=27). An analysis of variance test (ANOVA) was run on mercury concentration in fish by location and was found to have been significant at the $P<0.026$ level (Table 7). This significant difference was attributable to lower mercury levels in fish from Walung as opposed to those caught in Okat. There was no statistical difference in mercury levels in fish caught at Lelu harbor and Walung coastline. Therefore, the Okat harbor had fish with significantly higher mercury concentrations. This indicated that fish at Okat had higher than normal background mercury levels (Lelu and Walung mean values). For this to have occurred, there must have been a low level chronic mercury source at Okat which was probably related to the construction project.

There were different mean mercury concentrations in fish from different environments (Table 6). Fish caught on shallow and deep patch reefs had the highest mean mercury concentrations, while reef-flat specimens had the lowest mean values (Table 6). An ANOVA was run to ascertain if environment or habitat affected mercury concentrations in fish. There was a significant difference at the $P<0.008$ level for environment. This difference was attributable to higher mercury levels in fish caught on patch reefs as opposed to those caught on reef-flats (Table 7). Reef-flat fish specimens, which were caught primarily by gill net, had low to non-detectable mercury concentrations. These fish include invertebrate eaters, browsers and grazers which are, for the most part, wide-range movers. There were no significant differences in mercury concentrations in fish caught from various fringing reef environments (Tables 6 and 7). These fish had mercury levels which were intermediate between patch reef and reef-flat specimens. These fringing reef fish represented a wide range of trophic, habitat, aggregation and movement groups.

There was difficulty in obtaining sufficient fish specimens from all designated areas for mercury analysis. Therefore, fish catch was generally restricted to a few areas at each location (Table 6). Area 3 in Okat harbor (Figure 2) had fish with higher mercury concentrations than Okat area 10, Lelu areas 1, 3 and 5 (Figure 3) and Walung area 3 (Figure 5). Okat area 4 also had fish with higher mercury levels. Okat areas 3 and 4 were patch reefs which had common predatory fish. These patch reef species were generally located in small groups that were more or less sedentary or

Table 6. Mean concentration of mercury in fish tissue classified by location, environment, area, depth, genera and size.

	N	Mean (ppm)	Standard Deviation	STD Error of Mean
LOCATION				
Okat	44	0.09	0.15	0.02
Lelu	45	0.04	0.06	0.01
Walung	27	0.03	0.06	0.01
ENVIRONMENT				
Shallow Patch Reef	3	0.13	0.13	0.08
Deep Patch Reef	17	0.13	0.21	0.05
Fringing Reef (shallow harbor)	28	0.05	0.07	0.01
Fringing Reef (deep harbor)	11	0.06	0.08	0.02
Fringing Reef Margin	22	0.05	0.09	0.02
Reef Flat	35	0.02	0.05	0.01
AREA (for N>3)				
Okat: 3	12	0.18	0.23	0.07
Okat: 4	7	0.07	0.12	0.04
Okat:10	6	0.01	0.01	0.00
Okat:14	11	0.06	0.09	0.03
Lelu: 1	9	0.01	0.02	0.01
Lelu: 3	4	0.03	0.06	0.03
Lelu: 4	22	0.06	0.08	0.02
Lelu: 5	7	0.03	0.04	0.02
Walung: 1	6	0.05	0.07	0.03
Walung: 2	6	0.04	0.08	0.03
Walung: 3	15	0.02	0.03	0.01
DEPTH				
0-20 ft	51	0.04	0.07	0.01
21-50 ft	36	0.05	0.07	0.01
50-100 ft	26	0.11	0.18	0.03
>100 ft	3	0.04	0.07	0.04

Table 6. continued.

	N	Mean (ppm)	Standard Deviation	STD Error of Mean
GENERA (for N>3)				
Carangoides	6	0.03	0.04	0.02
Cephalophalis	23	0.11	0.19	0.04
Cheilinus	7	0.06	0.11	0.04
Epinephelus	9	0.06	0.10	0.03
Lethrinus	12	0.04	0.07	0.02
Lutjanus	12	0.05	0.08	0.02
Parupeneus	5	0.04	0.07	0.03
Scarus	4	0.00	0.00	--
Siganus	4	0.00	0.00	--
SIZE				
<100 cm	29	0.05	0.08	0.02
100-250 cm	52	0.04	0.07	0.01
251-500 cm	27	0.08	0.17	0.03
>500 cm	8	0.08	0.12	0.04

Table 7. Analysis of variance of mercury concentrations in fish tissue by location, environment, size and depth. Comparison of class levels were made to determine significant difference occurrences within sources. These significant differences are indicated by asterisks.

Source	DF	Type I SS	F Value	Significance Level	Means	Comparisons of Means Significant @ P<0.05
LOCATION	2	0.0828	3.77	0.026		
Okat					0.09	***
Lelu					0.04	
Walung					0.03	***
ENVIRONMENT	4	0.1541	3.66	0.008		
Patch Reef					0.13	***
Fringing, Shallow					0.05	
Fringing, Deep					0.06	
Reef Margin					0.05	
Reef Flat					0.02	***
SIZE	3	0.0360	1.04	NS*		
<100 cm					0.05	
100-250 cm					0.04	
250-500 cm					0.08	
>500 cm					0.08	
DEPTH	2	0.0759	3.44	0.035		
0-20 ft					0.03	***
20-50 ft					0.05	
>50 ft					0.10	***

* Not significant

limited-range movers. Fish specimens which were caught on the reef-flat at Okat area 10 had low-mercury concentrations.

Walung areas 1 and 2, which were fringing reef environments, had higher mercury concentrations in fish compared with area 3 fish, which were reef-flat specimens. Areas 1 and 2 were periodically subjected to turbidity plumes that originated at the Okat construction area and were carried to the areas by normal oceanic currents. Also, transient predatory fish species could have easily migrated to these Walung areas from the vicinity of Okat. These were only 3 reef-flat specimens in Walung that had detectable mercury levels: Epinephelus (grouper), Mulloides (goatfish), and Strongylura (needle fish). The goat fish (invertebrate eater) and needle fish (fish eater) are wide range movers. The grouper, which eats invertebrates and fish, is a sedentary predator.

In Lelu harbor, area 1 had the lowest mercury levels in fish, while area 4 had the highest levels. Area 1 specimens were caught primarily on the large central patch or fringing reef by gill net (Figure 3). Area 4 specimens were caught along a patch reef, from the harbor floor and along a fringing reef (Figure 3). There were common drift and debris lines in area 4 which flowed from the vicinity of water station 8 (Figure 3). This water station had the highest mercury concentration in seawater for Lelu harbor. Station 8 was located near the currently used Mobil fuel barge. Area 5 fish specimens had low mercury concentrations. These specimens were caught from the muddy harbor floor and along the edge of a shallow turbid patch reef. Area 3 fish had comparable low mercury concentrations as area 5. These fish were caught in the harbor mouth along the fringing reef within the major outflow water mass for Lelu harbor (Clayshulte, 1984b). Predatory fish had the highest mercury concentrations caught in Lelu harbor were predatory. These predatory fish included Sphyrna (hammerhead shark), Cephalophalis (grouper), Lethrinus (emperor), and Lujanus (snapper). These genera include both wide-range movers and sedentary species.

An ANOVA was run comparing fish caught in 3 depth zones for mercury concentrations. There was a significant difference by depth at the $P<0.035$ level (Table 6). This difference was attributable to higher mercury concentrations in fish specimens caught below 50 ft (16m) compared with fish caught in less than 20 ft (7m) of water. Fish caught at deeper depths were generally predators found in patch reef environments.

Fish specimen total weights were divided into four size classes for statistical analysis of size versus mercury concentration. These size classes were: 1) less than 100 g; 2) less than 250 g and greater than 100 g; 3) less than 500 g and greater than 250 g; and 4) greater than 500 g. These sizes ranges were used because they generally related to typical catch size groups for different fishery types in Kosrae. Fish length was compared to weight and was significantly correlated at the $P<0.01$ level; however, this was dependent, in part on fish species (Figure 7). The R-squared correlation for length versus weight was 0.54. Previous studies (Friberg and Vostal, 1972) have shown a positive correlation with mercury concentration and fish weight and size (a function of length and weight). An ANOVA was run comparing size classes and mercury content. There was no significant difference in mercury concentrations between different weight

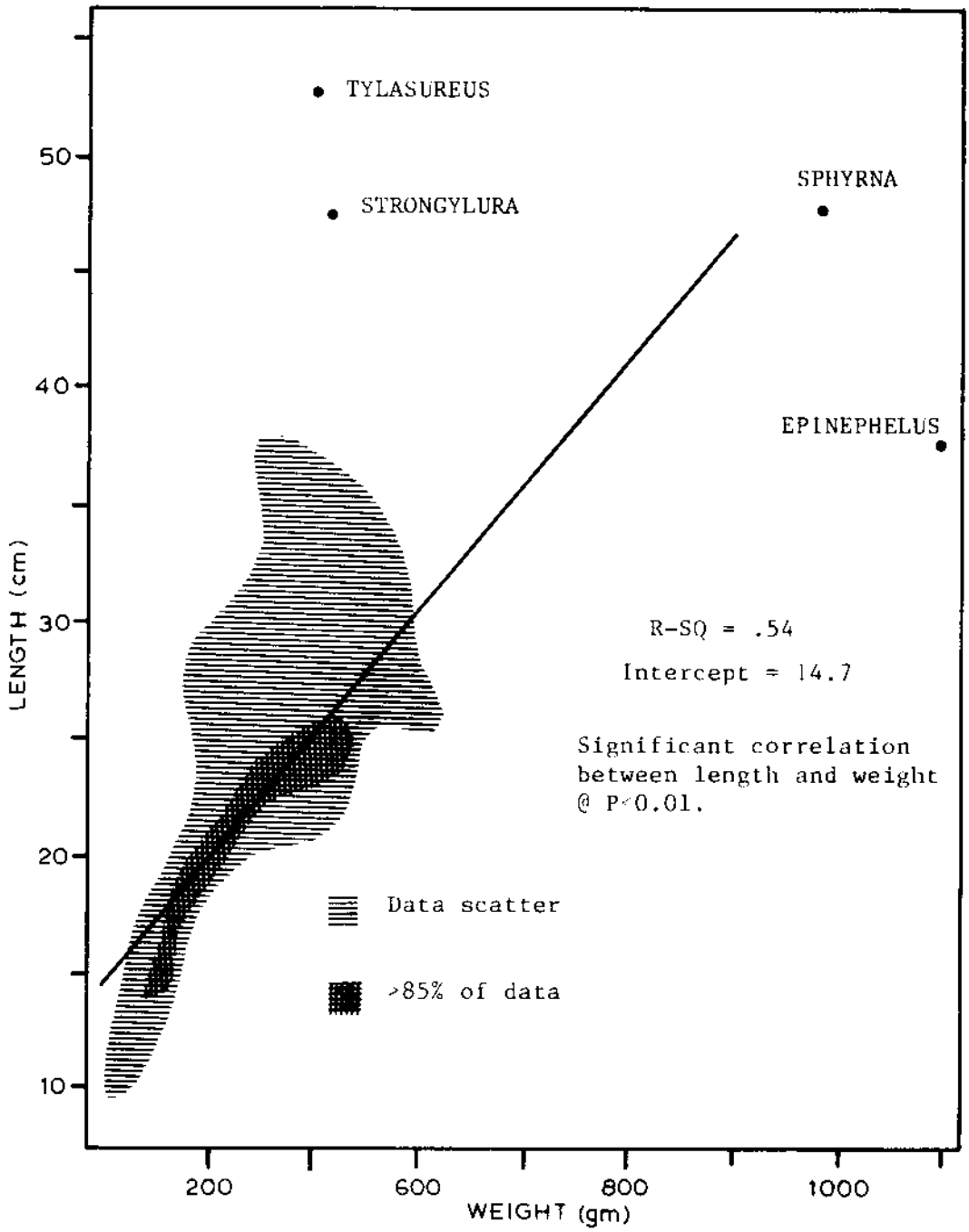

Figure 7. Length versus weight correlation of sampled fish.

and size classes of fish, although some larger predatory fish tended to have higher mercury concentrations (Figure 7; Table 6).

There were 9 fish genera which had at least 4 specimens analyzed for mercury content (Table 6). Specimens from the genus Cephalophelis (grouper) had the highest mercury concentrations. These predatory fish are found on patch reefs at deeper depths. These fish are non-aggregators which tend to be sedentary demersal feeders. There were 22 specimens of Cephalophelis analyzed for mercury concentration from Okat and Lelu harbors, with 11 specimens caught in each location. The mean mercury concentration in fish from Okat was 0.10 ± 0.12 ppm and from Lelu it was 0.06 ± 0.08 ppm. Okat specimens had higher mercury concentrations. There were 2 genera, Scarus and Siganus, that had no detectable mercury concentrations in any of the caught specimens (N=8). Scarus (parrot fish) are grazers and Siganus (rabbit fish) are browsers. The other genera which had low mercury concentrations were predators on other fish and invertebrates. Parupeneus species (goat fish) specialize on invertebrate food sources. These genera with low mercury concentrations tend to be non-aggregators or to form intermittant small groups. Lethrinus (emperors) are also sometimes found in schools. These genera are, for the most part, wide-range movers, except for the genus Epinephelus (grouper) which are sedentary species.

Water

Total and dissolved mercury samples were collected from near-surface marine waters at Okat, Lelu, Utwe and Walung (Figure 1). These water samples were taken from a variety of reef environments at these locations with 10 marine and estuarine samples taken at Okat; 10 marine and freshwater samples at Lelu; 8 marine samples at Walung; and 2 marine samples at Walung (Table 8). There was also a set of marine water samples taken for other heavy metal analyses in Okat as part of the airport runway and dock construction monitoring program (Table 9). Analyses were made for heavy metals arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. The TTPI marine water quality standards for total mercury is 0.10 µg/ℓ. This standard is the same as the detection limit for mercury (0.1 µg/ℓ). Total or dissolved mercury values shown in Tables 8 and 9 as <0.1 µg/ℓ are below the detection limit. The TTPI marine water quality standards for other heavy metals are shown in Table 9.

Total mercury analysis is a measure of the mercury content in solution within the water column, absorbed on suspended sediments and particulate matter and found in marine biotic components (plants and animals). This marine biota is primarily plankton which can include diatoms, algal fragments, filaments and unicellar species, copepods, crabs, shrimps, fish larvae, and other phytoplankton (plants) and zooplankton (animal). Suspended sediments, marine biotic components and most of the particulate matter can be taken out of a water sample by filtration. Analysis of filtered water sample for mercury is a measure of dissolved mercury within the water column and absorbed on very fine (<0.45 µ) particulate matter.

In a given marine water sample, the dissolved mercury concentration should be lower than or equal to the total mercury concentration. However,

Table 8. Total and dissolved mercury concentrations in marine and fresh water samples. Locations of sampling sites are shown in Figures 2 Okat, 3 Lelu, 4 Utwe and 5 Walung.

Location Date	Sample Site	Sample Time	MERCURY µg/ℓ Total Hg	Dissolved Hg
OKAT	1*	1440	1.2	0.4
13 July 1984	2	1430	0.4	0.3
	4	1400	< 0.1	0.4
	5	1345	0.3	1.0
	7	1330	1.9	0.2
	8	1300	0.1	0.5
	9	1505	0.2	0.4
	12	1800	0.4	0.2
	14	1605	0.9	1.1
	Bridge	1815	< 0.1	0.2
LELU	1	0750	0.2	0.2
18 and 19	2	0735	0.2	0.5
July 1984	3	1515	0.3	0.1
	4	0700	0.5	2.2
	5	1410	0.4	0.6
	6	0740	0.7	1.0
	7	1440	< 0.3	0.1
	8	0720	1.0	0.3
	9(stream)**	1430	< 0.1	0.3
	10(stream)***	1500	< 0.1	<0.1
UTWE	1	1155	0.2	0.1
(22 July 1984)	2	1135	0.7	0.4
	3	1140	0.8	0.3
	4	1145	< 0.1	0.4
	5	1125	0.3	0.3
	6	1115	0.4	<0.1
	7	1105	0.2	0.7
	8	1100	0.5	0.5
WALUNG	1	1200	0.4	0.8
(23 July 1984)	2	1430	0.9	2.0

* estuary, river channel within mangrove swamp.

** stream - fresh water stream flowing into harbor, sampled at oxidation ponds.

*** stream - fresh water stream flowing into harbor, sampled at water dam.

Table 9. Concentration of heavy metals in marine waters at Okat Harbor, July 12, 1984.

Sample Site	Arsenic (µg/ℓ)	Cadmium (µg/ℓ)	Chromium (µg/ℓ)	Copper (µg/ℓ)	Mercury (µg/ℓ)	Nickel (µg/ℓ)	Lead (µg/ℓ)	Zinc (µg/ℓ)
1	1.2	0.2	1.8	1.5	1.9*	<1.0	<1.0	1.6
2	2.3	0.2	1.7	2.1	0.8*	<1.0	<1.0	2.1
3	1.9	0.4	1.5	0.6	1.5*	<1.0	<1.0	1.1
4	2.1	0.2	1.3	2.4	0.9*	1.0	12*	5.3
5	1.0	0.6	1.7	3.1	0.9*	3.5*	<1.0	0.8
6	1.9	0.3	1.4	0.8	1.4*	4.2*	<1.0	5.6
7	1.9	0.2	1.7	0.6	2.1*	<1.0	3.1	6.9
9	2.0	0.4	1.4	1.1	1.4*	<1.0	2.8	13.0
13	2.2	0.2	1.4	2.0	1.1*	<1.0	1.3	1.7
14	2.1	0.4	1.5	0.4	0.5*	<1.0	<1.0	0.3
TTPI Standard	**10.0**	**5.0**	**50.0**	**10**	**0.10**	**2.0**	**10.0**	**20.0**

***exceeds TTPI standard.**

there are some dissolved mercury samples which are higher than comparable total mercury samples taken at the sample location (Table 8). These higher dissolved mercury concentrations are probably a result of contamination from the field filtration process, even though, care is taken to avoid contamination. Therefore, total mercury values provide better characterization of mercury concentrations in marine waters. Comparison of total and dissolved mercury concentration show that most of the mercury in Kosrae marine water is in the dissolved form (Table 8).

There were 2 sets of water samples taken from monitoring stations in Okat harbor for mercury and other metal analyses. These sets were taken on consecutive days under strong rising tide conditions. The mean total mercury concentration in marine waters for 12 July, 1984 was 1.25 µg/ℓ (N=10); for 13 July it was 0.54 µg/ℓ. The mean dissolved mercury for 13 July was 0.47 µg/ℓ. Prior to collection of the second set of water samples, there was heavy rainshower activity at Okat, which precipitated 2-3 inches of rain. Runoff from this rainfall caused large turbidity plumes within and flowing out of the harbor. The rainfall also caused reduced near-surface water temperatures (about ½°C) and salinities (about 3 parts per thousands). Probably as a result of this freshwater runoff, mercury concentrations in marine water at Okat were lower for the second set of water samples.

Mean total mercury concentrations for marine and estuarine waters at harbor locations were 0.90 µg/ℓ for Okat harbor, 0.45 µg/ℓ for Lelu harbor and 0.39 µg/ℓ for Utwe/Taf harbors. The average of 2 water samples from the Walung coastline analyzed for total mercury was 0.6 µg/ℓ. Freshwater samples taken from the Tofol stream, which discharges into Lelu harbor, were below the detection limit. A sample of brackish spring leakage along the landward edge of Okat mangroves (Figure 2; Bridge) was also below the detection limit.

Mercury concentrations in harbor and fringing coastal zones were in excess of the TTPI marine standard. There appeared to be a detectable background total mercury concentration in coastal marine waters around Kosrae. This background level was higher than anticipated for an oceanic island. Presumably, this mercury originated from weathering of upland volcanics and was transported by river discharges to coastal waters. However, mercury is not known to be a characteristic erosinal by-product from the type of volcanic rock found on Kosrae. There does appear to be some mercury introduced into the marine environment as a result of man related activities (i.e., construction, dredge and fill operations, ship docking).

There was significantly higher total mercury in marine waters at Okat harbor when compared to Lelu and Utwe harbors. The highest mercury concentration in Lelu harbor was found adjacent to the Mobil fuel barge on the south side of the harbor (Figure 3; station 8). The highest mercury concentrations in Taf harbor were found near a dredge operation (Figure 4; stations 2 and 3). Station 7 in Okat harbor (Figure 2) had the highest mercury concentrations for both Okat mercury analyses sets. This station receives water that flushes from the reef-flat adjacent to the runway and dock areas. This reef-flat has a large accumulation of dredge mud. Dredge

mud was continually resuspended into marine waters during tidal changes and washed out of the harbor in falling tides.

Locations of water quality stations in harbors were chosen to provide widest possible coverage at locations, to sample water from different reef environments and to assess areas near man-induced pertabations (i.e., dredging, docks). Similar reef environments and man-related activities were found in all 3 harbors. The following comparison of total mercury concentrations was made for related marine waters:

Total Mercury (µg/ℓ)

Okat	Lelu	Utwe	Environment
1.5	0.2	0.2	estuary
0.6	0.5	0.3	harbor entrance
0.8	0.2	0.7	dredge/dock area
2.0	1.0	0.8	reef margin in current line
0.5	0.3	0.4	patch reef

Total mercury was higher in all types of marine water at Okat when compared with Lelu and Walung. Reef margins which received current flows associated with man-related activities had the highest mercury concentrations at all 3 harbors. Okat estuary water had much higher mercury concentrations than estuaries in Lelu and Utwe. This Okat estuary monitoring station has had high mercury concentrations in previous analyses sets conducted for the runway and dock construction project. Sedimentation tube traps placed at this station in late 1982 and early 1983 had oil recoveries, which were believed to have originated from fuel oil spills at the construction site.

Mercury concentrations in marine waters were also measured for Truk State (FSM) and the Republic of Belau. These studies were also done in relation to airport construction water quality monitoring programs. Mercury concentration in marine waters in Koror-Toagel Mid Channel, Belau, in January 1981 and April 1982, were generally less than 0.1 µg/ℓ with a high concentration of 0.6 µg/ℓ (Zolan, 1983). Mercury concentrations were measured in marine water around the Moen, Truk, airport construction project from 1978 to 1982 (Clayshulte, 1983). In 1978, mercury concentration were less than 1.0 µg/ℓ at all stations except station 8. This station was near a sewer outfall and had a concentration of 29.0 µg/ℓ. This high value was not seen in subsequent surveys. Mercury concentrations in Truk marine water for 1981 and 1982 surveys were generally less than 1.0 µg/ℓ with high values of 1.6 µg/ℓ.

Mercury analysis conducted for the pre-construction assessment at Okat by Chun et al. (1979) recorded no detectable mercury in Okat harbor (Table 10). Mercury concentrations in marine water at Okat harbor in November 1982 were significantly higher when compared with the pre-construction assessment, Truk and Belau monitoring programs. November mercury values ranged from 2.3 to 7.1 µg/ℓ (Table 10). The mean mercury concentration in marine waters was 3.9 ± 1.8 µg/ℓ . A set of water samples were taken on July 7, 1983 to again quantify mercury concentrations at water quality stations (Table 10). High concentrations (in excess of the TTPI Marine

Table 10. Total mercury concentrations (µg/ℓ) in near-surface marine water at Okat Harbor water quality (WQ) monitoring stations. See Figure 1 for locations of WQ stations. The August 1979 sampling was done by Chun et al., (1979).

WQ Station	Aug. 1979	Nov. 1982	July 1983	July 1984
1	<0.1	6.6	0.4	1.9
2	-	7.1	1.0	0.8
3	<0.1	4.7	1.0	1.5
4	<0.1	4.6	2.0	0.9
5	<0.1	2.3	2.6	0.9
6	-	2.8	2.6	1.4
7	<0.1	3.0	1.6	2.1
8	-	3.1	0.4	-
9	-	2.6	1.4	1.4
10	<0.1	2.2	-	-
13	-	-	1.2	1.1
14	-	-	<0.1	0.5
Mean (µg/ℓ)	<0.1	3.9	1.3	1.3
± Standard deviation	-	1.8	0.8	0.5
Number of stations	10	10	11	10

Water Quality Standard) were found at all stations except station 14, which was below the detection limit. This station 14 sample represented oceanic water that had not been in contact with construction areas. The mean mercury concentration for this sampling set was 1.3 µg/ℓ. The July 1984 sampling set had the same mean mercury value as the July 1983 set (Table 10). These sampling sets were generally comparable between stations. Based on these water analyses sets, mercury entered the harbor water mass from the construction area. Those stations that were in a primary outflow current, which flowed through the dredge channel and past the dock area, had higher mercury concentrations. There was no obvious mercury source located at the construction site.

Research conducted on the deposition of mercury in the environment has shown that the majority of all mercury forms accumulate finally in bottom sediments (Barber et al., 1984; Brannon et al., 1980; Friberg and Vostal, 1972; Fujiki, 1980; Hartung and Dinman, 1972; McIntyre and Mills, 1978). Brannon et al. (1980) conducted experiments on the long-term release of heavy metals (including mercury) from marine sediments in harbor environments and found that mercury bound in sediments was not readily released back into the water column. Therefore, mercury in marine sediments, even when high, would pose very few long-term water quality problems. Experiments conducted by Fujiki (1980) on the accumulation of environmental methyl-mercury in marine fish showed that fish did not accumulate mercury to any great extent from the ingestion of suspended solids and bottom sediments.

Fish can directly accumulate mercury from marine water when it is in the form of methyl-mercury. Biological methylation of inorganic mercury to methyl-mercury is done by microorganisms or other chemical donors of the methyl group in marine sediments, the water column and, in some cases, within slime on the exterior of fish (Friberg and Vostal, 1972). The genus Cheilinus, which has exterior slime, caught in Okat had higher mercury concentrations, while Cheilinus caught in Lelu and Walung had no detectable mercury. Fujiki (1980) found that dissolved methyl-mercury in seawater was the major source for accumulation of mercury in marine fish. Fish and other invertebrate species (i.e., bivalves) concentrate mercury to high levels within tissue by absorbtion of dissolved mercury through gills or siphon tubes directly from seawater and to much lesser extents through digestive organs from ingestion of food-chain items, suspended matter and bottom sediments.

Fujiki (1980) found a background mercury concentration in marine fish from non-impacted sea environments around Japan of about 0.03 ppm (wet weight). Barber et al. (1984) found mercury levels in deep-sea fish ranged up to 1 ppm (wet weight) and concluded that potentially harmful concentrations of mercury can occur naturally in marine fish and were not a result of man induced contamination. Background levels of mercury in fresh tuna have been measured at an average 0.3 ppm (Officer and Ryther, 1981). The background mercury level for Kosrae inshore fish species found in non-impacted reef environments was 0.03 ppm (mean value for Walung coastline). The slightly impacted Lelu harbor had a background mercury level in fish of 0.04 ppm. These mercury levels compare with background levels found in Japan fish that were also caught in non-impacted sea environments.

CONCLUSIONS

Fish caught in Okat harbor had significantly higher mean mercury concentrations compared with fish caught in Walung, which was the control location. There was no statistical difference in mean mercury concentrations in fish caught at Lelu harbor and Walung coastline. Fish from Okat had higher than background mercury levels. Water analyses showed that the Okat area had total mercury concentrations in excess of the TTPI standard throughout the construction project. Mercury, in part, entered the harbor water mass from the construction area. There was no obvious low level chronic mercury source located at the construction site.

Mercury concentrations in fish caught from different reef environments, depths and areas were statistically analyzed for trends. These was a significant difference in mercury concentrations in fish from patch reef and reef-flat environments. Patch reef fish had much higher mercury concentrations. Significant differences in fish mercury concentrations occurred for specific areas within locations. There differences were partly attributable to reef environments, however, there were areas in specific water currents, which had fish with elevated mercury concentrations. Fish caught below 50 ft (16 m) had significantly higher mercury concentrations compared with fish caught in less than 20 ft (7 m) of water. Fish caught at deeper depths were generally predators found in patch reef environments.

Mercury concentrations in fish from different size classes and genera were analyzed for trends. There was no significant difference in mercury concentrations between different weight and size classes of fish, although large predatory fish tended to have higher mercury concentrations. Specimens of fish from the genus Cephalopholis (grouper) had higher mercury concentrations. Other genera which had consistently low mercury concentrations were also predators that feed on other fish and invertebrates. There were 2 genera , Scarus (parrot fish) and Siganus (rabbit fish), that had no detectable mercury concentration in any caught specimens. These genera are grazers and browsers.

Very large predatory fish (including sharks and eels) can have potentially higher mercury concentrations; however, periodic consumption of these predators should pose no significant health risk. The largest fish caught and analyzed for mercury was a small hammerhead shark (Sphyrna) which had a mercury concentration of 0.12 ppm (wet weight). The largest food fish caught was a grouper (Epinephelus) which had a mercury concentration of 0.07 ppm (wet weight).

Fish with higher mercury concentrations were associated with deeper water around patch reefs in Okat and Lelu harbors. This may also apply to fish caught in deeper water near harbor entrances. Specimens of fish caught on reef-flats had very low to non-detectable mercury concentrations. A commonly observed catch method on reef-flats in Okat was gill-netting. Consumption of these fish will pose no health risk. Fish caught in Lelu harbor by gill-netting also had low mercury concentrations.

Total mercury concentrations in Kosrae fish are attributable, in part, to natural background levels. There appears to be a minimal risk of future

mercury bio-accumulation in Kosrae fish, which could cause a health problem. We anticipate that most excess mercury in Okat marine waters should become bound within marine sediments. There should be only small amounts released into the water column by microorganism methylation. Assuming that there is no longer chronic mercury source associated with the airport and dock construction project, mercury levels in Okat fish should eventually return to a normal background level.

RECOMMENDATIONS

1. Notify the public that there is mercury in fish at Okat harbor at higher than background concentrations, but not at health risk levels.

2. A few large predatory fish and selected fish genera should be caught at Okat about every 6-months for a 2 year period and assayed for mercury concentration. These fish specimens could be caught by the Kosrae State Marine Resources Department and shipped frozen to a qualified laboratory for analyses.

3. A set of water samples should be taken for heavy metal analyses in 1985 and 1986 at water quality monitoring stations used in the airport runway and dock construction project. These samples should be analyzed for heavy metals: arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. These samples could be collected by the Department of Environmental Health and sent to a qualified laboratory for analyses.

4. A survey should be made to determine the yearly fish consumption rate by people in Kosrae. The rate should determine the weight of fish eaten per individual per day. The Kosrae State Marine Resources Department could assist in designing the survey.

5. The Kosrae State Department of Environmental Health should conduct an inspection of the airport and dock site for potential pollution sources which could have contributed to the mercury problem and take any necessary remedial action to remove these pollutant sources.

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