STORMWATER DISCHARGES FROM WETLANDS IN AMERICAN MEMORIAL PARK, SAIPAN: IMPACT ON FISH MERCURY LEVELS IN RECEVING WATERS

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Disclaimer

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Abstract

The American Memorial Park (AMME) in Saipan was established in 1978 to commemorate US soldiers and civilians killed on island during WWII. The land was occupied by the US Navy immediately after WWII and used as a motor pool and maintenance facility. It also served as a disposal site for unexploded ordnance and residual wartime munitions, as well as a general dumping ground for toxic chemicals and other hazardous wastes. Mercury levels in surface soils within the park commonly exceed 100 ng/g and are largely attributed to fulminated mercury and metallic mercury released from surplus ammunitions detonated and/or buried on the property. Two wetlands exist within the park. One is natural while the other was created in the 1990s as part of a flood mitigation program for Garapan village. Both wetlands discharge excess stormwater into separate nearshore embayments. Mercury and selenium levels in a popular table fish (*Lethrinus harak*) from both embayments were therefore of interest.

Overall, sixty fish were examined in this study. Their fork lengths and body weights ranged from 9.5-29.3 cm and 15-426 g respectively. Total mercury levels in axial muscle tissue ranged from 0.009-0.493 µg/g wet weight and were positively correlated with size. Marginally higher values were found in fish from the embayment receiving drainage from the *Natural Wetland*. These findings were in line with mercury profiles noted in sediments from the area. Mercury levels in ocean fish typically range from 0.001-0.100 µg/g depending upon size and trophic level. USEPA advises that fish beyond this upper limit should not be consumed on an unrestricted basis. Normalization of our data to a 20-cm fish length matched this value, which implies that consumption of *L. harak* beyond this size be limited. However, the selenium data suggested otherwise. Selenium is known to be protective of mercury toxicity and current research indicates that all fish are safe to eat providing their selenium-mercury molar ratios are equivalent (1:1) or in molar excess for selenium. Selenium concentrations in fish examined during the current study ranged from 112 ng/g to 368 ng/g and were consistently in molar excess of mercury. The ratio between these two elements was, however, strongly size-dependent and generally lower in larger fish. *Lethrinus harak* exceeding 33-cm fork lengths were predicted by regression techniques to exhibit Se:Hg ratios of <1 in some individuals, based on confidence interval inspections. Fortunately, *L. harak* above 30-cm fork lengths are rarely encountered in Saipan’s nearshore waters.

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Preamble

The American Memorial Park (AMME) is a 133-acre (54 ha) parcel of land that borders the central region of Saipan Lagoon (Fig. 1). It was constructed in 1978 under the administrative control of the US National Park Service (NPS) to commemorate US soldiers killed on Saipan during WWII. Located in the village of Garapan, the land upon which the park now sits was occupied by the US Navy immediately after the war and aerial photographs taken in 1948 reveal military buildings scattered over much of the property. The area served primarily as a motor pool and maintenance and repair facility back then, as well as a refueling station for military and civilian personnel (Ogden 1998). Allotments were also set aside for the stockpiling and disposal of unexploded ordnance and other residual munitions (AMPRO 2005). The indiscriminate dumping of garbage on the property was commonplace and continued until well into the 1970s (Raulerson and Rinehart 1989). The impact of these past land-use activities upon the edible quality of fisheries in adjacent coastal waters prompted the investigation described herein.

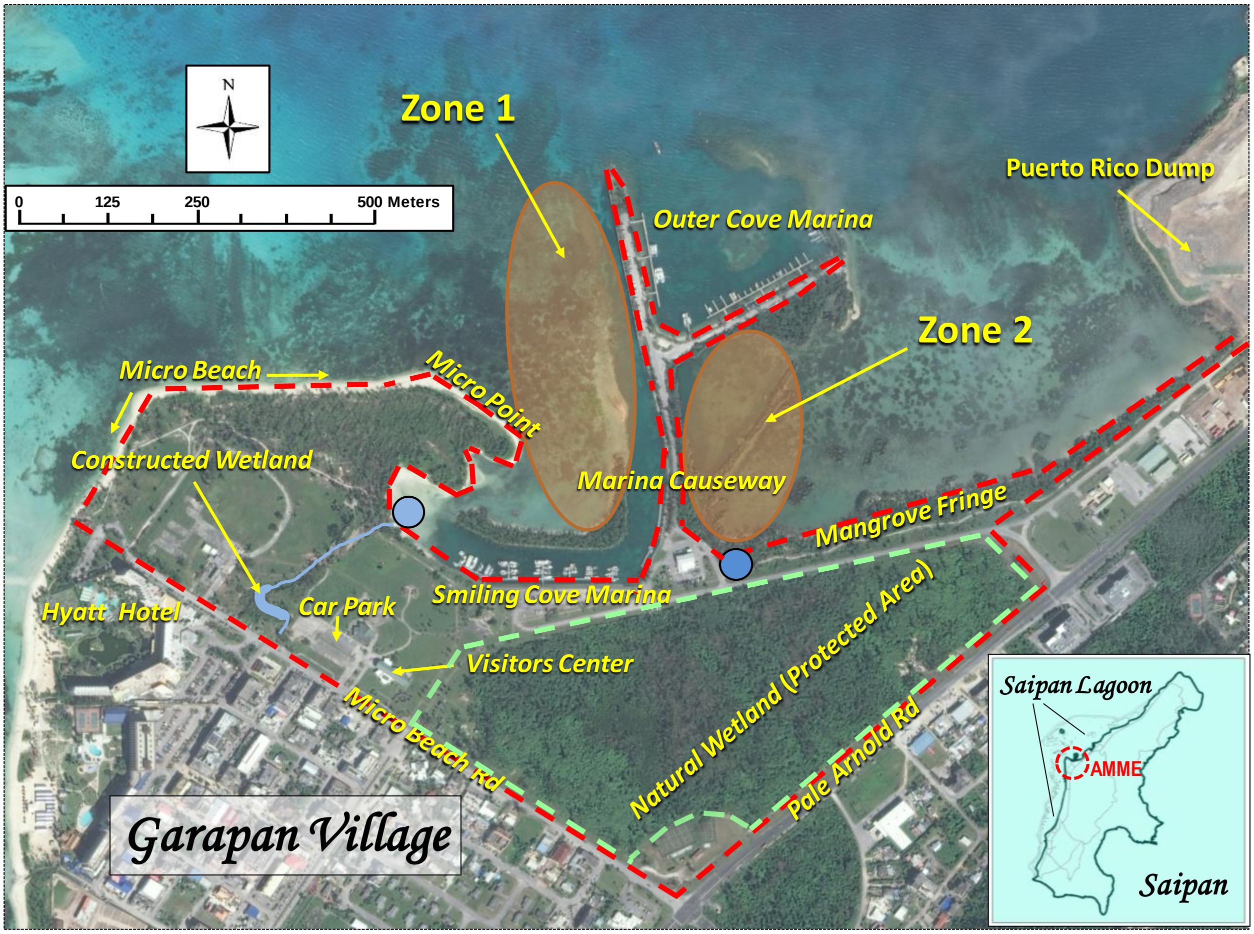

Figure 1: Image of American Memorial Park (AMME) and adjacent areas with inset of Saipan Island. Dashed red and green lines indicate AMME and natural wetland boundaries respectively. Blue circles represent stormwater discharge points into the ocean. Fish and sediment samples examined during the present investigation were collected from Zones 1 and 2.

Wetlands

There are two wetlands within the AMME, and both discharge excess stormwater directly into the ocean. One of these wetlands is natural while the other was built in the 1990s as part of a flood mitigation plan for northern Garapan (Perreault 2007). The *Constructed Wetland* is located on the western side of the property and is essentially an excavated pond that receives runoff from the Garapan commercial center. During periods of heavy rain, the pond overflows and channels excess water into the ocean beside *Smiling Cove Marina*. The receiving waters are largely contained within a shallow embayment that is partially enclosed by land and land-based structures (Fig. 1). Water circulation within this area is highly restricted. Hence recalcitrant contaminants entering the system are not readily voided by normal tidal movements.

The *Natural Wetland* is situated on the southeastern side of the property and is a triangular mosaic of secondary forest interspersed with emergent wetland. It provides critical habitat for many avian species and other indigenous wildlife and is now a designated protected area (Williams 2007). Drainage from this wetland exits the property through a stormdrain abutting the eastern wall of the *Marina Causeway*. The shallow embayment to the east of this man-made structure is partially bounded by *Outer Cove Marina* to the north, and the southwestern edge the Puerto Rico Dump to the east (Fig. 1). Water circulation within this embayment is extremely restricted and mudflats prevail along much of the shoreline and for some distance out to sea. Consequently, the bay likely acts as a permanent sink for persistent pollutants flushed into it.

Primary Mercury Sources

Mercury has no known vehicular uses and is not normally detected in urban runoff (USEPA 1983, Makepeace 1995, Fulkerson *et al.* 2007). In Saipan, however, it is commonly encountered in stormwater discharges entering the ocean along the western seaboard (Environet Inc. 2007). This anomaly reflects the widespread use of fulminated mercury and metallic mercury in WWII munitions (US Navy 1946, 1947), coupled with the heavy bombardments that heralded the arrival of US Marines in 1944 (Denton *et al.* 2014). Wartime ordnance in various states of decay continue to be unearthed in AMME (AMPRO 2005) and elsewhere on Saipan and continue to pose potentially long-term source of mercury contamination island-wide.

The detonation and burial of residual ordnance in the AMME has certainly left behind a mercury footprint throughout the park that presents a potential threat to fisheries resources in adjacent waters. Mercury concentrations approaching 200 ng/g were recently discovered in soils from the *Natural Wetland* and represent a five-fold increase above natural baseline values (Denton *et al.* 2016). According to Fergusson (1990), soils containing mercury concentrations above 100 ng/g dry weight, are considered significantly contaminated.

Smoke stack emissions and toxic ash from a medical waste incinerator at the *Commonwealth Health Center,* in Garapan, contaminated much of the village surrounds over a 20-year period. The facility was finally closed in 2006 for violations of the Clean Air Act (Saipan Tribune 2005). Fallout from the incinerator undoubtedly contributed to mercury loads periodically flushed into the *Constructed Wetland* from the streets of northern Garapan. The residual ash washed into the ocean just south of AMME, and by 2005 had raised mercury concentrations significantly in nearshore fisheries. Levels were shown to have declined 2-years later (Denton *et al.* 2011a & b).

Study Objectives

This exploratory investigation examines mercury and selenium concentrations in surface sediments and fish from nearshore waters receiving stormwater discharges from the *Constructed*

Wetland and *Natural Wetland* within AMME. Surface sediments were selected for study because they provide a useful means of identifying recent inputs of persistent contaminants from land-based sources (Ingersoll 1995). They also play an important role in releasing sorbed contaminants back to the overlying water and to the indigenous biota (Baudo and Muntau 1990). Selenium was of interest because of its essentiality and protective effect against mercury toxicity (Pařizek and Ostadelova 1967, Ralston 2008).

The thumb-print emperor, *Lethrinus harak*, was the fish of choice in this study because it is one of the most commonly encountered emperor fish in Saipan Lagoon and is a popular table fish among local fishers (Taylor and McIlwain 2010). It also has a restricted foraging range, which makes it ideal for monitoring spatial differences in mercury abundance over relatively short distances. Moreover, WERI has amassed a considerable bank of mercury data for this species from clean and contaminated locations within Saipan Lagoon – (Denton *et al.* 2010, 2011a, 2018a).

The primary tasks of this assignment were:

1. To make a preliminary assessment of mercury and selenium levels in surface sediments within each embayment, starting from stormwater discharge points and progressing seaward along transects perpendicular to the shore.
2. To examine mercury levels in axial muscle of *Lethrinus harak* from each embayment.
3. To compare the data with levels reported in similar matrices from elsewhere, and finally:
4. To evaluate potential health risks associated with the unrestricted consumption of *L. harak* from the study area before and after taking their selenium loadings into account.

Study Rationale

In 2004, several hundred high explosive projectiles were unearthed during the construction of the AMME *Visitors Center* car park. A magnetometer sweep of the area suggested that several hundred more projectiles or parts thereof, lay buried outside of the construction area (AMPRO 2005). Any mercury releases from these projectiles could easily be transported into adjacent coastal waters given the hydrological dynamics of the area (Perreault 2007). In fact, there is some evidence to suggest that this is already happening with relatively high levels of mercury recently reported in fish from the Micro Beach area that borders the western boundary of AMME (Fig. 1). In 2007, for example, 21 specimens of *Lethrinus harak* were captured from Micro Beach. Their fork lengths and axial muscle mercury concentrations ranged from 15.3-27.5 cm (median: 21.7 cm) and 0.063-0.346 µg/g wet weight (median: 0.128 µg/g) respectively. Since mercury levels in fish are growth-dependent, it is common practice to normalize the data to a standard fish length for comparative assessment purposes. The standard fish length adopted in this instance was 20 cm and provided a normalized value of 0.121 µg/g (95% CL: 0.103-0.141 µg/g). Representatives from relatively clean waters in the northern half of Saipan Lagoon typically yield normalized values for this size fish of ~0.050 µg/g. Further south, corresponding values are ~20% lower (Denton *et al.* 2018a). The Micro Beach fish were thus considered moderately contaminated with mercury.

In 2007, two *L. harak* specimens were captured from *Micro Point* at the eastern end of *Micro Beach* (Fig. 1). The fork lengths of these two fish were 13.9 and 28.5 cm, and their axial muscle mercury concentrations were remarkably high at 0.144 and 1.185 µg/g respectively. Both values are unmatched by any other similar sized *L. harak* specimen analyzed to date. It is intriguing to speculate, therefore, that mercury inputs from the *Constructed Wetland* in AMME were responsible for this anomaly. The following study was implemented to shed light on this issue.

In 2012, four soil samples were taken for heavy metal analysis from the *Natural Wetland* and mixed wet forested areas on the southeastern side of AMME. The data were weighed against ecological soil screening levels (Eco-SSLs) developed by the USEPA (2005). Accordingly, ecological benchmark exceedances were identified for mercury in all samples, and for cadmium, lead, copper and zinc in two of them (Denton and Gawel unpublished data). The relatively high levels of mercury (116-176 ng/g) were indicative of significant mercury contamination (Fergusson (1990). Background mercury levels in Saipan soils are usually less than 50 ng/g and typically hover around 30-35 ng/g (Denton *et al.* 2016). Assuming these data are reflective of soil mercury levels throughout the *Natural Wetland*, drainage waters from the property might well become enriched with this element as they migrate towards the coast.

In 2016, a series of nearshore sediment samples were taken for metal analysis from around the seaward perimeter of AMME. The investigation was part of a wider study to evaluate the potential impact of past land-use practices on aquatic resources within the area and focused primarily on bivalves (Denton *et al.* 2018b). The highest sedimentary mercury concentrations to emerge from this study were confined to the muddy substrates east of the *Marina Causeway*. Samples retrieved next to the now closed Puerto Rico dump; an old military field hospital site; and the AMME *Natural Wetland* stormdrain, yielded the highest mercury concentrations of 27.3, 31.1 and 37.3 ng/g respectively. Background mercury levels in these substrates were less than 10 ng/g. The comparatively high mercury value found in the AMME stormdrain deposits is noteworthy and suggests this element may indeed be slowly moving down the hydrological gradient from the *Natural Wetland* into adjacent nearshore waters. Determining the extent of this contamination is of primary concern considering the *Marina Causeway* is well patronized by Saipan residents who fish from its walkways and harvest clams from adjacent mangroves and seagrass beds. It is also worth remembering here that mercury has caused more problems to consumers of fish than any other inorganic compound (Irukayama *et al.* 1961).

Study Benefits

The findings reported here complement earlier studies conducted closer to the dump (DEQ 1987, Denton *et al.* 2001, 2006, 2008, 2009, Ridolfi Inc. 2007, Denton *et al.* 2018b) and should command the interest of public health officials, regulators, and environmental managers throughout the region. In addition, it adds significantly to the contaminant database required for the future assessment and regulation of pollution problems in the region, including a sensibly planned and readily implemented monitoring program. The development of such a database is vital for the protection and sustainable development of aquatic resources in the CNMI.

Methods, Procedures and Facilities

The study areas examined in this work lie either side of the *Marina Causeway* and are approximately delineated in Fig. 1 as Zone 1 and Zone 2. Each zone receives exclusive drainage from the *Constructed Wetland* and *Natural Wetland*, respectively. Sediments in both zones are primarily composed of bioclastic (biogenic) carbonates. At the time of collection, Zone 1 sediments were dominated by poorly sorted muddy sand, shell gravel and calcareous algal remnants, while those retrieved from Zone 2 were almost entirely composed of mud.

Surface sediment samples (~0-5 cm depth) were taken for analysis at ~25-m intervals either side of the *Marina Causeway*. Three replicate sediment samples (~100 g each) were taken within a 3-m diameter circle at each sampling point and later pooled for analysis. The samples were scooped up in hand-held, pre-cleaned, plastic vials (70 ml) and drained of excess water before freezing for transportation and storage purposes. In the laboratory, the sediments were air dried at 30°C in clean

Ziploc bags, then disaggregated by gently crushing each bag and its contents between finger and thumb, before sieving. Only sediments passing through a 1-mm Nylon screen were retained for mercury and selenium analyses.

All representative fish samples were caught by hook and line at night while foraging among nearshore seagrass beds. They were placed on ice as soon as possible after capture and transported to the laboratory in insulated containers. Mercury and selenium levels were determined in axial muscle taken immediately below the dorsal fin to the lateral line of each fish.

All analytical work was carried out at the WERI Water Quality Laboratory, at the University of Guam, where adequate support facilities, infrastructure, essential chemicals and items of equipment necessary for the study existed. The analytical procedures for mercury and selenium followed established protocols as previously outlined in Denton *et al.* (2018b). All QA/QC procedures, including duplicates, blanks, matrix spikes, and accuracy and precision verifications using standard reference material, were rigidly adhered to.

Principal Findings and Significance

The mercury and selenium data for sediments (Table 1) and fish (Tables 2-5) are expressed on a dry weight and wet weight basis, respectively. The fish data are also illustrated graphically where appropriate (Figs 2-5). The findings were evaluated by reference to levels found in similar matrices from clean and contaminated waters elsewhere.

Sediments

Mercury: Sediment concentrations of mercury in unpolluted, non-geochemically enriched areas, usually do not exceed 30 ng/g (Knauer 1976, Bryan and Langston 1992, Benoit *et al.* 1994), and may be as low as 1 ng/g in clean bioclastic sediments (Denton *et al*. 2014). In the current study, mercury levels found in Zone 1 sediments ranged from 2.5-19 ng/g and generally decreased with increased distance offshore (Table 1). Higher levels were frequently encountered in Zone 2 (15-38 ng/g) with deposits nearest the AMME stormdrain yielding the highest concentrations. Interestingly, the seaward attenuation of mercury was more marked in Zone 2, possibly reflecting greater compositional consistency of sediments between sites. Denton and Morrison (2009) reported mercury levels of 1.6-14 ng/g in a mix of biogenic and lithogenic sediments from a relatively clean coastal environment on Guam. They also noted higher sedimentary mercury levels in deposits closest to groundwater intrusion and freshwater runoff. From the foregoing, it seems reasonable to conclude that surface sediment examined during the present investigation were only mildly enriched with mercury compared with much higher levels reported in the general area 2-3 decades ago (Denton *et al*. 2001, DEQ 1987).

Selenium: Selenium levels determined in sediments during the current study ranged from 16-217 ng/g west of the *Martina Causeway* and 75-263 ng/g to the east. Lowest levels were confined to sediments closest the stormwater outlets in each zone. Levels in the remaining samples showed no obvious relationship with distance offshore. Little comparative data exist in the literature for selenium in carbonate-rich sediments, although NOAA scientists published selenium levels recorded in coral reef sediments from four different locations in Puerto Rico. Their reported means ranged from 150-330 ng/g (Whitall *et al.* 2014). The NOAA *National Status and Trends* (NS&T) program has been compiling sediment contaminant data from sites throughout the U.S since 1984. The program's national median for selenium in marine sediments currently stands at 330 ng/g (Apeti *et al.* 2012). Thus, selenium concentrations measured during the present study generally rank among the lower sediment values reported for US waters.

Table 1: Total Mercury and Selenium Levels in Surface Sediments from Zones 1 and 2

Seaward Distance from Discharge Point (m)[a]	ng/g dry wt.		Seaward Distance from Discharge Point (m)[a]	ng/g dry wt.	
	Hg	Se		Hg	Se
Constructed Wetland ⟶ (Zone 1)			*Natural Wetland* ⟶ (Zone 2)		
0[b]	8.89	16.0	0[b]	37.5	75.0
25	3.52	78.6	25	22.9	205
50	4.39	108	50	24.0	363
75	21.5	217	75	25.5	289
100	16.3	165	100	20.2	260
125	11.5	164	125	21.0	139
150	6.03	90.9	150	14.7	203
175	18.8	206	175	16.0	223
200	19.1	174	200	16.6	191
225	19.9	167	225	15.8	199
250	11.8	144	250	17.2	274
275	6.63	153	275	16.1	233
300	4.17	97.7	300	18.6	242
325	4.46	183	325	15.2	199
350	4.46	141	-	-	-
375	3.31	71.6	-	-	-
400	2.74	59.3	-	-	-
425	3.60	90.0	-	-	-
450	3.43	102	-	-	-
475	4.33	136	-	-	-
500	2.53	62.7	-	-	-

[a] Samples taken approximately parallel to the *Marina Causeway* (Fig.1)

[b] From Denton *et al.* (2018)

Fish

Mercury: Total mercury levels in marine teleosts normally range between 0.001 and 0.100 µg/g wet weight depending upon age and trophic level (Holden 1973). During the present study, 90% of all fish of 20-cm fork length or less, yielded mercury values below this upper limit. In contrast, almost half of those above 20 cm exceeded it (Tables 2 and 3). The highest mercury value recorded was 0.493 µg/g wet weight in a 29.3 cm specimen from Zone 1.

Average mercury concentrations in a standardized 20-cm fish from each zone were estimated by linear regression techniques following log-transformation of the datasets. Values of 0.087 µg/g and 0.126 µg/g wet weight were obtained for Zone 1 and Zone 2 fish respectively, with corresponding confidence limits (95%) of 0.069-0.109 µg/g and 0.077-0.205 µg/g. The broader confidence limits around the Zone 2 estimate reflects the smaller sample size and limited size range of fish captured (Table 3). However, when the datasets are plotted together on a single graph, 75% of Zone 2 samples clustered above the regression line (Fig. 2), which suggests that fish from the latter region are marginally more contaminated. Regression analysis of the combined datasets yields an average mercury concentration of 0.100 µg/g for a standardized 20-cm fish length (95% CL: 0.083-0.121 µg/g).

According to USEPA's fish consumption guidelines for the general population, fish with methylmercury concentrations in their muscle tissue of less than 0.088 µg/g wet weight may be eaten on an unrestricted basis (USEPA 2000). In contrast, 8-oz fish meals containing the same concentration as the 29.3 cm specimen noted above, should not be consumed more than once a week; and not more than once a month for women of childbearing age, nursing mothers or sensitive individuals. Mercury in fish occurs predominantly in the highly toxic methylated form and typically accounts for 80-90% of total mercury in axial muscle tissue (Storelli *et al.* 2005).

Fish from the study area thus show mild to moderate mercury enrichment, and specimens exceeding 20-cm fork length should not be consumed on an unrestricted basis, based on mercury concentrations alone (Table 4). Given the location of the study area and proximity to several possible mercury sources, the results seem hardly surprising, and, if anything, are better than expected.

Selenium: Selenium is an essential dietary trace element to humans and plays an important role in antioxidant defense systems, thyroid activity, immune responses, brain function and cardiac health (Raymond and Ralston 2004, Mozaffarian 2009). Levels in ocean fish normally run from 100-1000 ng/g with most species yielding values in the mid to lower part of this range (Guns *et al.* 1992, Plessi *et al.* 2001, Burger and Gochfield 2013, Yamashita *et al*. 2013). Total selenium concentrations measured in fish during the present study ranged from 112 ng/g to 368 ng/g and are therefore in agreement with this statement. Interestingly, fish from both zones yielded almost identical concentration ranges (Table 2 and 3) with no evidence of size-dependency.

Selenium's protective effect against mercury toxicity has captured public attention in recent years, especial among voracious consumers of seafood. Fish have a high propensity for mercury, and current USEPA doctrine dictates that specimens with more than 0.088 µg/g in their edible tissue should not be eaten on an unrestricted basis (USEPA 2000). Recent research by Ralston and coworkers suggests otherwise, providing selenium-mercury molar ratios in the fish consumed are equivalent (1:1) or in molar excess for selenium (Ralston *et al.* 2008).

Selenium levels in fish examined over the current investigation were consistently in molar excess of mercury with Se:Hg ratios varying from 1.3-40 (Tables 2 and 3). Ratios were clearly size-dependent with lower values generally occurring in larger fish (Figs. 4). Fish up to 33 cm in length were predicted to have Se:Hg molar ratios above 1 with 95% certainty (Table 5, Fig. 5). Since all fish examined were smaller than this critical length, it seems relatively safe to assume that they were all safe to eat based on their selenium concentrations.

Concluding Remarks:

Surface sediments within the study areas were only mildly enriched with mercury and levels in emperor fish were lower than anticipated based on previous findings. We conclude that this anomaly is due in part to severe storm activity over Saipan in recent years. Typhoon Soudelor (July 2015), for example, brought heavy winds and torrential rains that induced massive topographical changes to the island's nearshore environment. Surface sediments in both study zone embayments were flushed seaward during the height of the storm and replaced by fresh deposits as the storm abated. Such natural cleansing mechanisms have been reported elsewhere (Denton and Morrison 2009) and play a vital role in mitigating contaminant build-up.

Table 2: Total Mercury and Selenium Levels in Axial Muscle of Fish from Zones 1

Specimen	Fork length (cm)	Wet wt. (g)	ng/g wet wt.		nM/g		Se:Hg Molar Ratio[a]
			Hg	Se	Hg	Se	
Zone 1							
1	9.5	15.0	14.0	196	0.07	2.48	36
2	10.5	20.2	8.97	142	0.04	1.80	40
3	11.0	23.6	7.05	112	0.04	1.42	40
4	11.5	27.9	47.3	173	0.24	2.19	9.3
5	12.0	32.8	14.7	157	0.07	1.98	27
6	12.5	36.2	57.9	368	0.29	4.66	16
7	13.0	40.7	55.7	169	0.28	2.15	7.7
8	13.0	39.6	14.6	145	0.07	1.84	25
9	13.5	46.7	16.5	185	0.08	2.34	28
10	14.0	47.4	57.0	241	0.28	3.05	11
11	15.0	56.9	106	223	0.53	2.83	5.3
12	15.0	61.2	19.9	138	0.10	1.75	18
13	15.5	70.5	61.6	193	0.31	2.44	8.0
14	15.5	68.3	64.3	191	0.32	2.42	7.6
15	15.5	69.0	37.9	220	0.19	2.79	15
16	15.8	65.3	67.3	255	0.34	3.22	10
17	16.0	72.2	64.9	241	0.32	3.05	9.4
18	16.0	79.3	52.8	203	0.26	2.57	10
19	17.0	75.4	12.1	170	0.06	2.15	36
20	17.0	87.0	105	169	0.52	2.14	4.1
21	17.5	99.7	133	215	0.66	2.72	4.1
22	18.0	105	97.4	268	0.49	3.40	7.0
23	18.2	119	81.9	151	0.41	1.91	4.7
24	19.5	140	109	214	0.54	2.71	5.0
25	20.0	162	96.7	208	0.48	2.64	5.5
26	20.0	153	51.5	203	0.26	2.57	10
27	20.5	136	95.8	196	0.48	2.48	5.2
28	21.0	180	93.2	173	0.46	2.19	4.7
29	21.0	180	89.6	267	0.45	3.38	7.6
30	21.0	169	65.2	199	0.33	2.52	7.7
31	21.0	180	42.2	188	0.21	2.38	11
32	21.0	180	84.9	153	0.42	1.93	4.6
33	21.5	185	145	234	0.72	2.97	4.1
34	22.0	203	34.1	197	0.17	2.49	15
35	22.0	204	72.4	214	0.36	2.71	7.5
36	22.5	206	154	229	0.77	2.90	3.8
37	22.5	206	180	182	0.90	2.31	2.6
38	22.7	225	130	146	0.65	1.84	2.8
39	23.5	245	326	206	1.62	2.61	1.6
40	29.3	426	486	256	2.42	3.24	1.3

Table 3: Total Mercury and Selenium Levels in Axial Muscle of Fish from Zone 2

Specimen	Fork length (cm)	Wet wt. (g)	ng/g wet wt.		nM/g		Se:Hg Molar Ratio[a]
			Hg	Se	Hg	Se	
Zone 2							
1	15.5	75.0	38.3	134	0.19	1.69	9
2	15.5	64.0	27.6	143	0.14	1.81	13
3	18.0	115	134	173	0.67	2.19	3.3
4	20.0	136	153	162	0.76	2.05	2.7
5	14.5	54.4	40.9	149	0.20	1.88	9.2
6	15.8	68.9	29.7	146	0.15	1.85	12
7	14.5	49.7	60.1	162	0.30	2.05	6.9
8	14.0	52.0	114	118	0.57	1.49	2.6
9	14.5	62.3	62.2	173	0.31	2.19	7.1
10	15.0	63.0	86.0	156	0.43	1.98	4.6
11	15.5	67.1	85.6	124	0.43	1.57	3.7
12	16.0	81.3	65.9	350	0.33	4.43	13
13	16.0	81.3	63.9	334	0.32	4.23	13
14	15.3	62.9	82.5	346	0.41	4.38	11
15	16.0	76.2	69.6	321	0.35	4.07	12
16	17.0	85.5	87.5	289	0.44	3.67	8.4
17	17.5	88.2	111	305	0.55	3.86	7.0
18	17.0	89.5	45.5	348	0.23	4.41	19
19	18.0	107	83.1	320	0.41	4.05	10
20	20.0	156	135	320	0.67	4.05	6.0

[a] Molar ratios calculated by multiplying Se and Hg concentrations by 78.96 and 200.59 respectively

Table 4: Predicted Size-Dependent Mercury Concentrations for Fish from Zones 1 and 2, and Consumption Limit Recommendations Based on USEPA Criteria

Fork Length (cm)	Hg (µg/g wet weight)[a]	8-oz Fish Meals/Month[b]	
	Mean (95% Confidence Limits)	General Pop.	Sensitive Individs.[c]
10	0.016 (0.011-0.023)	>16	>16
15	0.047 (0.039-0.055)	>16	16
20	0.100 (0.083-0.121)	16-16	4-8
25	0.181 (0.133-0.247)	8-12	4-4
30	0.294 (0.192-0.450)	4-8	2-3
31	0.321 (0.205-0.501)	4-8	1-2
32	0.349 (0.219-0.556)	4-8	1-2
33	0.379 (0.233-0.610)	4-4	1-2
34	0.410 (0.247-0.680)	4-4	1-2
35	0.443 (0.262-0.749)	3-4	1-2
40	0.632 (0.342-1.166)	2-4	0.5-1
41	0.674 (0.359-1.266)	2-4	0.5-1
42	0.719 (0.377-1.371)	2-3	0.5-1
43	0.765 (0.395-1.483)	1-3	0.5-1
44	0.814 (0.414-1.601)	1-3	0.5-1
45	0.864 (0.443-1.725)	1-3	0.5-1

[a] Derived from Fig. 2 regression equation; [b] Adopted from USEPA (2000) and modified to include both mean and upper 95% confidence interval for each fish size listed; [c] Includes women of child bearing age, nursing mothers, and sensitive adults.

Table 5: Predicted Selenium-Mercury Molar Ratios for Fish from Zones 1 and 2.

Fork Length (cm)	Se:Hg Molar Ratio
	Mean (95% Confidence Limits)
10	27 (19-40.0)
15	10 (9.0-12)
20	5.4 (4.4-6.5)
25	3.2 (2.3-4.3)
30	2.1 (1.4-3.1)
31	1.9 (1.2-3.0)
32	1.8 (1.1-2.8)
33	1.7 (1.0-2.7)
34	1.5 (0.93-2.5)
35	1.4 (0.85-2.4)
40	1.1 (0.57-1.9)
41	0.99 (0.53-1.9)
42	0.94 (0.50-1.8)
43	0.89 (0.46-1.7)
44	0.84 (0.43-1.6)
45	0.80 (0.40-1.6)

Derived from data shown in Tables 2 and 3, and presented in Fig. 3

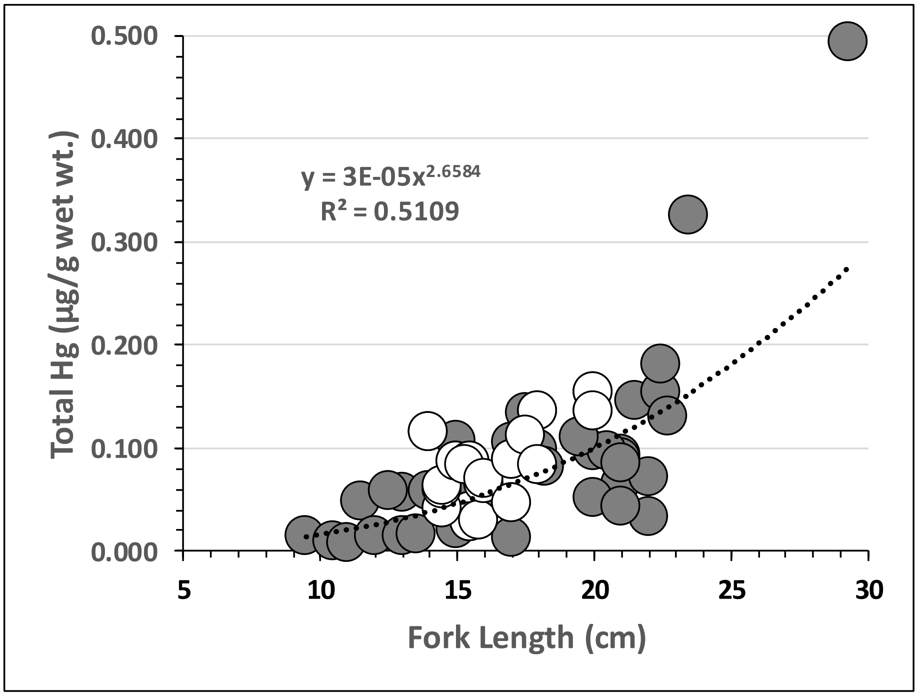

Figure 2: Mercury levels in fish axial muscle plotted against fork length. Zone 1 and 2 fish represented by grey and white plots, respectively. Regression line of best fit (power curve) derived from all data plots.

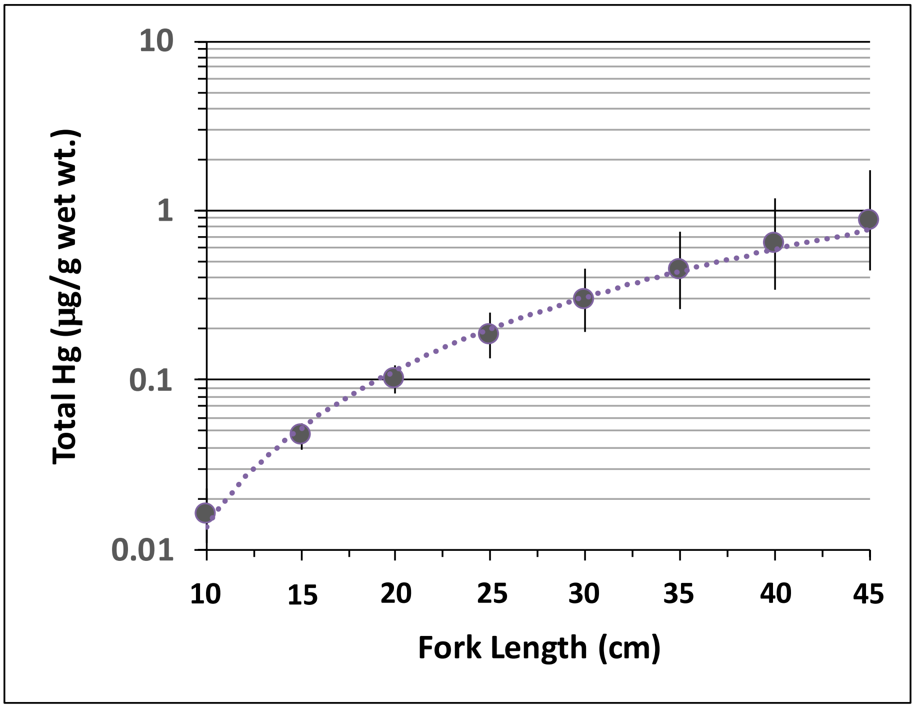

Figure 3: Predicted mean mercury concentrations in fish axial muscle plotted against fork length. Plots and 95% confidence limits (vertical bars) calculated from regression equation shown in Fig. 2.

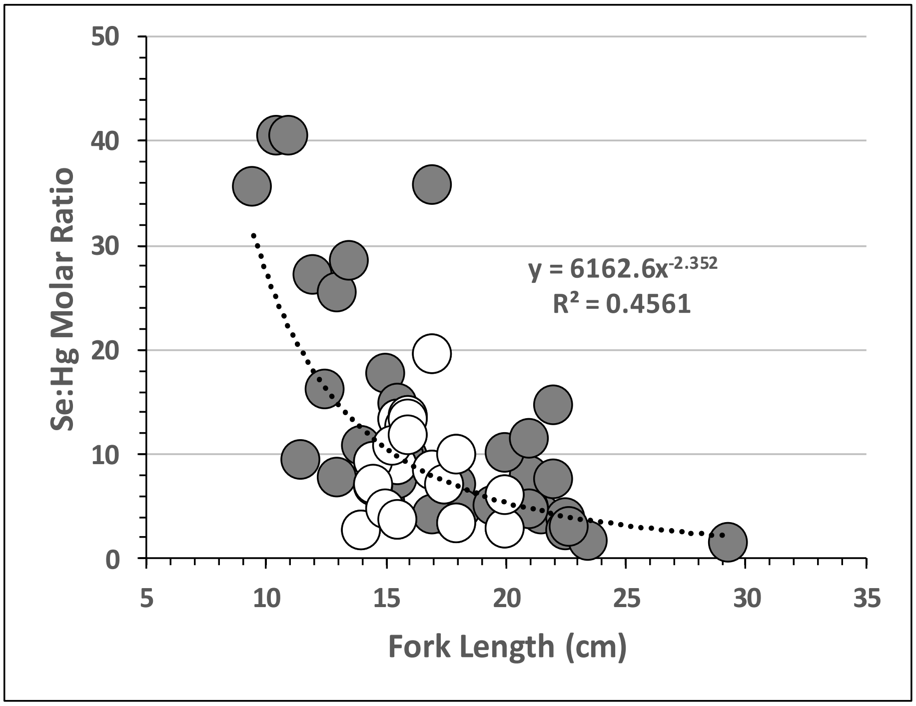

Figure 4: Selenium-mercury ratios in fish axial muscle plotted against fork length. Zone 1 and Zone 2 fish represented by grey and white plots, respectively. Regression line of best fit (power curve) derived from all data plots.

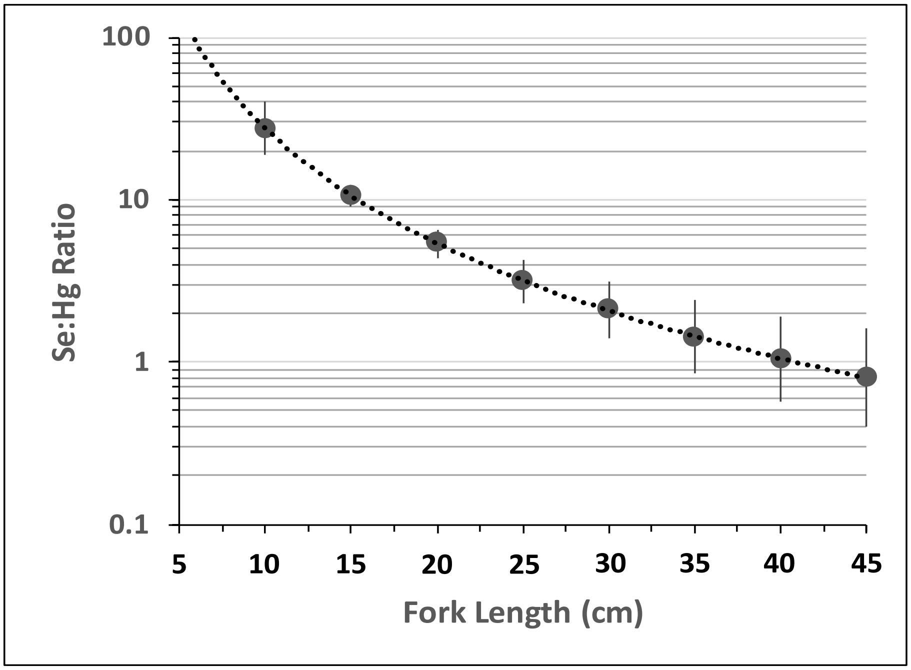

Figure 5: Predicted mean selenium-mercury molar ratios in fish axial muscle plotted against fork length. Plots and 95% confidence limits (vertical bars) calculated from regression equation shown in Fig. 4.

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