A Risk Assessment of Methylmercury to Fish in South Florida

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ABSTRACT

A limited set of studies have evaluated the hazards of methylmercury (MeHg) to fish. The range of lowest effect residues reported was 470 ng/g wet weight (ww) to 12,000 ng/g ww based on tissue burdens, and 567 to 54,000 ng/g based on dietary burdens. The measured endpoints ranged from molecular alterations (e.g., metallothionein and testosterone levels) to reproductive impacts (e.g., sex ratio and spawning success). Based on those data, biological effect thresholds that were generated for the determination of risk from MeHg ranged from 323 to 529 ng/g ww based on tissue burdens, and from 345 to 718 ng/g based on dietary burdens. Mercury (total mercury - THg) monitoring data for fish collected from south Florida between 1999 and 2009 were retrieved from the South Florida Water Management District's DBHYDRO database for comparison to the effect thresholds. Six different species comprised that data set: bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), redear sunfish (*L. microlophus*), spotted sunfish (*L. punctatus*), eastern mosquitofish (*Gambusia holbrooki*), and warmouth (*L. gulosus*). Approximately 20 percent of the data showed THg concentrations greater than the lowest effect threshold concentration for MeHg (323 ng/g ww). A probabilistic approach to risk analysis, which incorporates Monte Carlo sampling of the entirety of both the effects and monitoring data sets, indicated a relatively low likelihood (3.5%) that any individual fish is at risk from MeHg. Segregating the monitoring dataset by species, year, and location revealed that risk varied with each of these factors.

METHODS

The effect of MeHg upon fish was evaluated by searching the literature for studies that dosed fish with MeHg and documented statistically significant effects. Studies that dosed fish with Hg were not included in this analysis since it is presumed that the majority (~90 percent) of Hg in fish is in the form of MeHg (CH_3Hg^+) (USEPA 1997). Only effects that are classified as ecologically important (survival, growth, reproduction, development, behavior) were selected for this analysis (Beckvar et al. 2005). All fish mercury data used in this analysis were retrieved from the South Florida Water Management District's DBHYDRO database for the years 1998-2008. Data for all species except largemouth bass are THg for whole fish. Largemouth bass data are for filets.

Threshold effect levels reported in Table 2 were derived using methods outlined in Beckvar et al. (2005) for effect levels reported in the literature. The simple rank, empirical percentile, and tissue threshold effect level derivations used functions available in Microsoft Excel®. The cumulative distribution function derivation was carried out using Crystal Ball®.

Risk probability was determined through the Monte Carlo sampling capability of Crystal Ball®. It was assumed that the fish monitoring data were lognormally distributed with the shape characterized by the data mean and standard deviation. All risk analsyses were based on tissue-based threshold levels since no presumption was made regarding the dietary preferences for the focal species.

Table 1. Lowest Effect Residue Levels Reported in Literature for Methylmercury

Dietary Lowest Effect Residue (ng/g ww)	Tissue Lowest Effect Residue (ng/g ww)	Measurement Endpoint (s)	Reference
		Molecular Level	
3,930	3,557	Decreased testosterone in male fathead minnow (FHM)	Drevnick and Sandheinrich 2003
870	917	Decreased estradiol in female FHM	Drevnick and Sandheinrich 2003
		Tissue Level	
870		Apoptotic follicular cells in FHM ovaries	Drevnick et al. 2006
		Organism Level (survival, growth, behavior)	
1,900	470	Decreased mummichog survival	Matta et al. 2001
987	2,370	Reduced walleye growth	Friedmann et al. 1996
567	1,310	Reduced GSI in juvenile male walleye	Friedmann et al. 1996
959	536	Affected schooling behavior in golden shiners	Webber and Haines 2003
		Population Level (reproduction)	
870	890	Delayed FHM spawning	Drevnick and Sandheinrich 2003
3,930	4,225	Decreased FHM spawning success	Sandheinrich and Miller 2006
5,600	1,100	Mummichog sex ratio skewed towards females	Matta et al. 2001
54,000	12,000	Decreased egg fertilization success in mummichog	Matta et al. 2001

Table 2. Derived Biological Effects Threshold Levels for Protection of Fish

Threshold Derivation Approach [1]		Dietary-based Threshold Levels [2]	Tissue-based Threshold Levels [2]
Simple Rank	Lowest "low-effect residue"	567	470
	Highest "no-effect residue"	455	440
Empirical Percentile	5th percentile [3]	718	500
	10th percentile [3]	870	529
Tissue Threshold-effect Level (t-TEL) [4]	t-TEL	345	377
Cumulative Distribution Function	5th percentile [5]	275	336

[1] From Beckvar et al. (2005)
[2] Units ng/g wet weight as methylmercury
[3] Generated using "percentile" function in Microsoft Excel®
[4] Generated using the LER-L (15th percentile lowest effect residue) and NEL-M (50th percentile no-effect residue). The LER-L and NER-M were 870 and 137 ng/g, and 660 and 215 ng/g for dietary-based and tissue-based threshold levels, respectively.
[5] Percentiles generated using Crystal Ball®. The dietary-based level was based on an average of 6,771 ng/g (stdev = 15,754) while the tissue-based level was based on an average of 2,737 ng/g (stdev = 3,500). A lognormal distribution was assumed for both residue data sets.

Figure 1. Total Mercury in All Fish Species Relative to Threshold Effect Levels

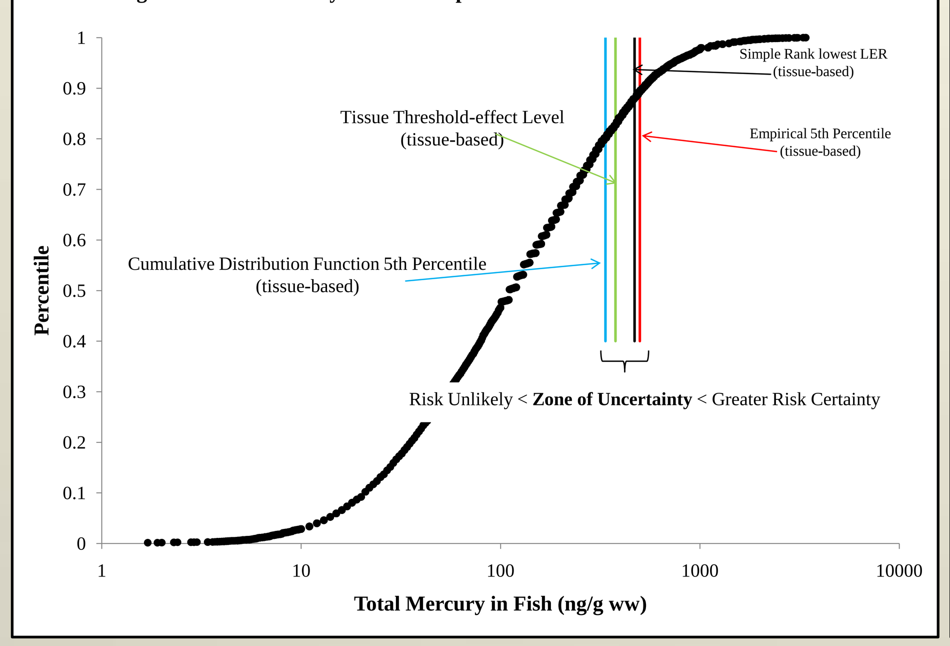


Figure 2. Total Mercury in Fish by Species Relative to Threshold Effect Levels

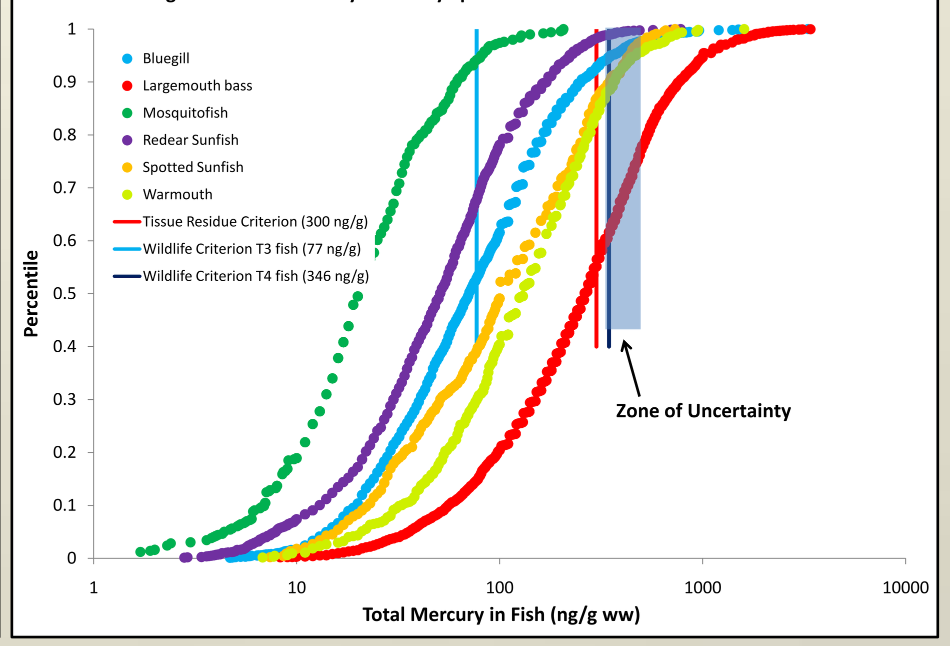


Figure 3. Tissue Burden Threshold Effect Levels in Relation to Spatial and Temporal Variation of Total Mercury Burdens in Largemouth Bass

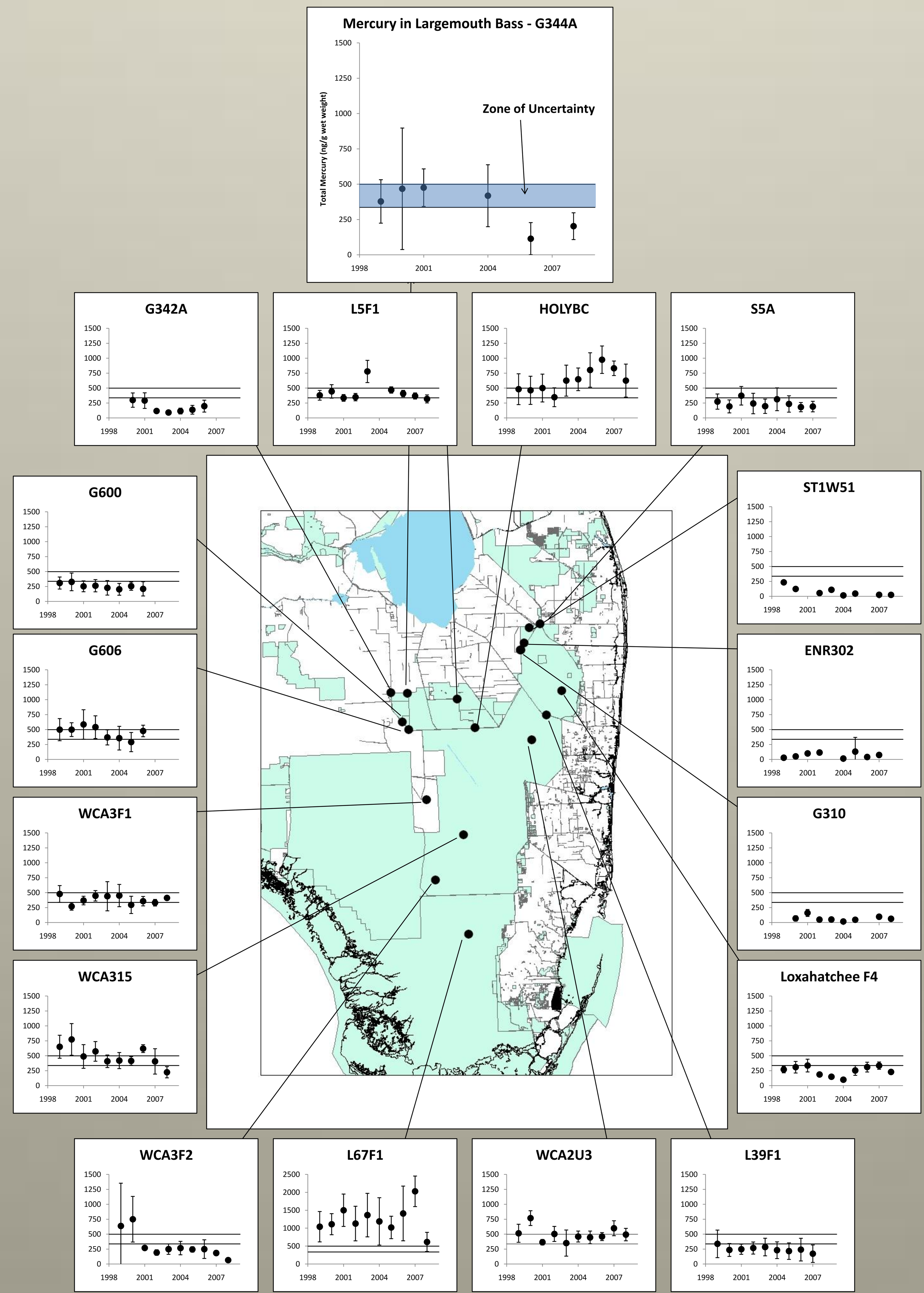
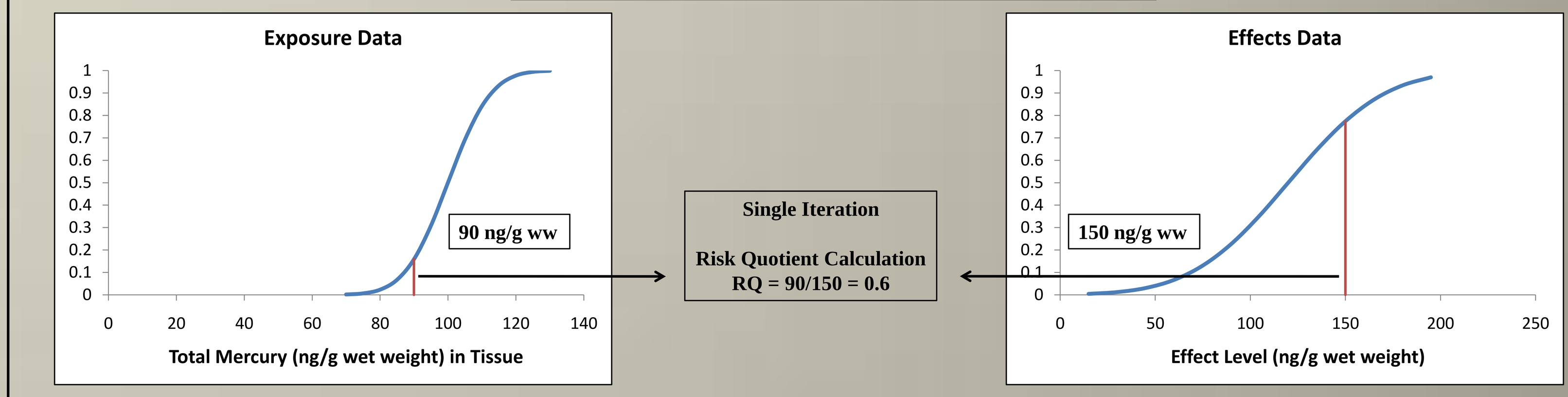


Table 3. Risk Probabilities Based on Monte Carlo Sampling.

Scenario [1]		Average Total Mercury Whole Fish (ng/g ww)	Standard Deviation	Risk Probability [2]
All Species, All Locations Combined		213.9	284.4	3.2
Mosquitofish, All Locations Combined		28.7	28.5	0.1
Red-eared Sunfish, All Locations Combined		73.2	75.4	1.4
Bluegill, All Locations Combined		115.2	152.8	1.2
Spotted Sunfish, All Locations Combined		149.7	136.2	1.6
Warmouth, All Locations Combined		175.4	161.6	2.2
Largemouth Bass, All Locations Combined		359.6	357.9	7.4
Location L67F1	**Largemouth Bass**	1,248.1	603.6	36.1
	Bluegill	487.9	395.8	11.1
Location HOLYBC	**Largemouth Bass**	630.4	290.2	16
	Bluegill	193.3	122.2	2.1
Location WCA2U3	**Largemouth Bass**	545.4	289.2	13.6
	Bluegill	211.9	118.6	2.4

[1] All scenarios combine residue data among all years (1998-2008).
[2] Data distributions for all scenarios assumed to be lognormal.

Monte Carlo Sampling for Risk Probability – a snapshot



DISCUSSION

- Table 1 reports the effect levels reported in the literature. It is evident from the effects data that sufficient MeHg exposure can adversely affect fish reproduction; statistically significant effects are reported from the molecular (steroid hormone levels) to the population (skewed sex ratios) levels of biological organization.
- Table 2 presents the different derived Threshold Effect Levels. The premise of the "Threshold Effect Level" is that, if concentrations in the matrix of interest do not exceed the threshold, then risk is unlikely. The "tissue-based" threshold values establish a tissue-based protection level while the "dietary-based" values establish a consumption-based protection level. The range of derived effect threshold levels based on tissue residue levels (336 – 529 ng/g) is narrow. As a result, the degree of protection afforded by the different threshold levels is unlikely to differ significantly.
- Figures 1 and 2 relate the derived tissue-based lowest-effect residue (LER) levels for MeHg to the THg levels measured in fish. Based on Figure 1, between 11 and 20 percent of the sampled fish in south Florida are at risk. By species, the greatest risk is for largemouth bass while the lowest risk is for mosquitofish (Figure 2). While it is assumed that the majority of the mercury detected in fish is comprised by MeHg, the fact that the actual proportion comprised by MeHg varies with trophic level (Baeta et al. 2006) and tissue (Baeta et al. 2006, Lasorsa and Allen-Gill 1995) will lead to variation in the risk estimation.
- Figure 2 also indicates the proportion of fish with THg levels that exceed threshold levels for protection of humans and piscivorous wildlife as reported by the U.S. Environmental Protection Agency (1997). Since most of the derived threshold values for fish are greater than those reported by the USEPA, ensuring that THg levels in fish at the most equal USEPA's guideline levels will be protective of fish in south Florida – provided the effect levels in the literature are accurate.
- Figure 3 relates the risk for largemouth bass to location and year. Mercury contamination in fish clearly varies spatially and temporally (Gabriel et al. 2009), which has been reported for other organisms and for the abiotic environment in south Florida (Liu et al. 2009, Rumbold et al. 2002, Gilmour et al. 1998). Concordantly, as shown in Figure 3, risk to fish from mercury will also vary spatially and temporally.
- Table 3 reports the probability that fish are at risk from MeHg. Generally, the relative risk among species and locations as indicated by Figures 1 and 2 are reflected by the risk probabilities shown in Table 3. However, the probabilities in Table 3 take into account the variability of mercury residues and effect levels providing a level of objectivity not evident for risk estimation using the LER.
- The significance of a risk probability value is often classified subjectively. It could be subject to (1) management considerations, (2) toxic endpoint, or (3) statistical comparison. The levels of risk apparent for fish in south Florida varies widely from almost absent for a species such as the mosquitofish (0.1 percent for all locations and years) to quite apparent for a species like largemouth bass (36.1 percent @ location L67F1). But the risk level is not spatially homogenous with some areas having considerably greater mercury contamination (L67F1 – Everglades National Park) compared to others (ST1W51). At those locations where risk is apparent, the effect will likely be manifested as reproductive impairment – absent population adaptation to chronic exposure over multiple generations.

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