# Appendix J.  Review of Effects on Wildlife

This is a review of the toxic effects of methylmercury on wildlife.  This review includes evidence of methylmercury exposure on wildlife in California, including in threatened and endangered species.  Table J-1 presents protective methylmercury thresholds for wildlife.  These thresholds were compiled from the literature for comparison to the water quality objectives in the Provisions.  Overall, there is more evidence of methylmercury toxicity from areas outside of California and in controlled laboratory studies.  This evidence has been used to suggest that California wildlife is suffering methylmercury toxicity as well.

The most recent analyses by USFWS on the potential impact of methylmercury to threatened and endangered species included seven threatened and endangered species of concern (USFWS (2003):

Bald eagle (*Haliaeetus leucocephalus,* delisted in 2007)
California least tern (*Sterna antillarum browni*)
California Ridgeway's Rail (*Rallus obsoletus*)*
Light-Footed Ridgeway's Rail (*Rallus obsoletus levipes*)*
Yuma Ridgeway's Rail (*Rallus obsoletus yumanensis*)*
Western snowy plover (*Charadrius alexandrinus nivosus*)
Southern sea otter (*Enhydra lutris nereis*)

*Ridgeway's rails were formerly named clapper rails, *Rallus longirostris.*

The synopsis below includes studies on exposure and effects in California Ridgeway's rail and snowy plover in California, and in bald eagles outside of California.  Little to no information was found on exposure and effects in the wild for the Southern sea otter, California least tern, light-footed Ridgeway's rail and the Yuma Ridgeway's rail.

## J.1 Overview of Typical Toxic Effects on Wildlife

The species most at risk for methylmercury toxicity are generally piscivorous (fish-eating) wildlife, because methylmercury tends to accumulate to very high concentrations in the aquatic food web (USFWS 2003).  However, some terrestrial songbirds have recently been found with higher mercury levels than fish eating birds  because they feed on predatory invertebrates, like spiders, which lengthens their food chain and increases the bioaccumulation of methylmercury (Cristol et al. 2008).  Methylmercury is also toxic to the fish themselves.  The effects on fish, including impaired reproduction, are described at the end of this appendix.

In birds, methylmercury has been found to alter birdsongs and impair the ability to fly (Carlson et al. 2014, Hallinger et al. 2010).  Chronic effects of methylmercury have been found in adult birds.  For instance, in southern Florida, great white herons liver mercury levels (6 mg/kg) correlated with mortality from chronic diseases (Spalding et al. 1994). Weight loss, neurologic, and immunologic effects were observed in captive great egrets fed a diet with 0.5 mg/kg methylmercury (Spalding 2000a, Spalding 2000b). Reproduction is one of the most sensitive endpoints to methylmercury toxicity. Effects in birds include reduced hatching due to early mortality of embryos, fewer eggs laid, changes in pairing behavior and territorial behavior (Wolfe et al. 1998, Barr 1986, Heinz 1979, Frederick and Jayasena 2011).

In mammals, such as mink and otter, methylmercury toxicity is primarily manifested as central nervous system damage. These effects include sensory and motor deficits and behavioral impairment (Wolfe et al. 1998, Scheuhammer et al. 2007). The neurological effects can be followed quickly by death (Dansereau et al. 1999).

Studies have measured mercury and or methylmercury in different biological materials, such as blood, feathers, and eggs. The advantage of measuring mercury in feathers is that it does not harm wildlife. However, other measures are more closely related to the site of the toxicity and therefore they are likely a better predictor of toxicity. There is no established relationship between each of these measurements (e.g. mercury in feathers to mercury in blood), so each measurement can only be compared to the mercury concentrations in the same material.

## J.2 Exposure and Effects in Wild Birds

### *J.2.1 California – San Francisco Bay Area*

Davis et al., and Ackerman et al., recently published reviews on bioaccumulation. Both reviews include a summary of the effects in wildlife within the San Francisco Bay. The San Francisco Bay has been the subject of many studies on methylmercury bioaccumulation. Much of the information summarized in this appendix on the San Francisco Bay area is from the two reviews by Davis et al. and Ackerman et al. (Davis et al. 2012, Ackerman et al. 2014).

California least terns, a federally endangered species, are piscivores that forage extensively in the shallows of the open Bay (Ehrler et al. 2006). Limited data are available for methylmercury in eggs of California Least Terns because of their small population and endangered status. However, terns as a group may be somewhat more sensitive to methylmercury than other species (Heinz et al. 2009).

Forster's tern (*Sterna forsteri*), Caspian tern (*Sterna caspia*), American avocet (*Recurvirostra americana*), and black-necked stilt (*Himantopus mexicanus*) all feed and breed primarily in and around estuarine managed ponds in San Francisco Bay. Extensive studies of methylmercury exposure and risk in these species, including sampling of eggs and blood have been conducted (Eagles-Smith and Ackerman 2010, Eagles-Smith et al. 2009). Nearly half (48%) of breeding Forster's Terns and approximately 5% of avocets, stilts, and Caspian Terns exceeded 3 ppm of mercury in blood (Eagles-Smith et al. 2009), a concentration at which common loons (*Gavia immer*) experienced a 40% loss in reproduction (Evers et al. 2008a). Estimated reproductive risks to the terns, avocets, and stilts based on egg mercury concentrations are very similar.

Annual mean mercury concentrations in Forster's Tern eggs ranged from 0.9 to 1.6 mg/kg from 2005 to 2009. This exceeds the threshold of 0.9 mg/kg that was derived by correlating hatching and nest success with egg mercury concentrations (Eagles-Smith and Ackerman 2010). Mercury concentrations in blood and eggs have been consistently higher in Lower South Bay near the town of Alviso, which is located downstream of the New Almaden mercury mine.

California Ridgeway's rail is a federally endangered bird species that inhabits tidal marsh only in San Francisco Bay. Recovery of this endangered species may be impeded by mercury contamination. A study from 1991 to 1999 concluded that methylmercury was a likely cause of the unusually high rates (31%) of nonviable Ridgeway's Rail eggs (Schwarzbach et al. 2006). Mercury was found in rail eggs above effects thresholds (0.5–0.8 mg/kg fresh wet weight (fww); Fimreite 1971; Heinz 1979) at all of the marshes studied; mean egg mercury concentrations for each marsh ranged from 0.3 to 0.8 mg/kg (Schwarzbach et al. 2006). Egg-injection studies have indicated that hatchability in Ridgeway's Rails is relatively sensitive to methylmercury (Heinz et al. 2009).

The Pacific Coast population of snowy plover is listed as threatened by USFWS. Elevated mercury concentrations were found in failed eggs of snowy plovers at Point Reyes National Seashore. Failed snowy plover eggs at Point Reyes Beach in the 2000 breeding season contained elevated mercury concentrations when compared with snowy plovers in southern California. The egg hatchability rate of 79% for snowy plovers was unusually low. Normal egg hatchability rates for most birds, including snowy plover, are usually greater than 90%. Mercury concentrations in individual snowy plover eggs ranged from 0.25 - 3.1 mg/kg (fww). The mean mercury egg concentration of 1.07 mg/kg (fww) in nests with failed plover eggs was probably high enough to account for egg failure through direct toxic effects to plover embryos compared to thresholds in the literature (0.5–0.8 mg/kg fww; Fimreite 1971; Heinz 1979). The authors hypothesized that the high mercury may have been a result of dead marine mammals that washed ashore. Marine mammals tend to have high methylmercury concentrations in their tissues and the plovers could have foraged on the invertebrates (e.g. maggots) that lived off the decomposing carcasses. Human disturbance is also known to have a negative impact on plover reproduction by driving the adults away from the nest, leaving the chicks vulnerable.

Tidal marsh song sparrows (*Melospiza melodia*) are not piscivores, but insectivores. These birds eat aquatic insects in bays and wetlands, which can have more methylmercury than terrestrial insects because aquatic environments tend to promote methylmercury bioaccumulation. Average song sparrow blood mercury concentrations in the South Bay ranged from 0.1 to 0.6 ppm near the marsh. More than half the sparrows were above a 0.4 ppm blood mercury threshold which results in a 5% reduction in songbird reproduction (Jackson et al. 2011) in both 2007 and 2008 (Grenier et al. 2010). Sparrow methylmercury exposure also correlated with the percent of mercury in sediment that was present as methylmercury. The song sparrow is listed by the California Department of Fish and Wildlife(CDFW) as a state species of special concern (CDFW 2008).

Riparian songbirds (song sparrows) in some streams of the Bay Area have mercury levels that are associated with reduced reproductive success (Robinson et al. 2011). The greatest risk, where the mean adult song sparrow blood mercury concentration (1.66 ppm) would be associated with more than a 25% loss in reproductive success (using a threshold from Jackson et al. 2011), occurred at a site downstream of New Almaden. Sites upstream of the mercury mines also had elevated mercury in blood, though to a lesser degree.

Eggs of the piscivorous double-crested cormorant (*Phalacrocorax auritus*) have been monitored for more than a decade as an indicator of accumulation of methylmercury and other contaminants in the open areas of San Francisco Bay. While mercury concentrations in eggs from San Pablo and Suisun Bays (ranging from 0.28 to 0.70 mg/kg wet weight in composite samples) have tended to be at or below adverse effects thresholds for reproductive impairment in mallards and ring-necked pheasants (0.5–0.8 mg/kg fww; Fimreite 1971; Heinz 1979), eggs from South Bay (ranging from 0.56 to 1.05 mg/kg) have tended to exceed those levels (Grenier et al. 2011). Cormorants are relatively insensitive to methylmercury toxicity compared to other species (Heinz et al. 2009), so it does not appear likely that these concentrations are harmful to the population (Grenier et al. 2011).

*J.2.2 California – Outside the San Francisco Bay Area*

Ackerman et al. measured mercury in grebe blood in 25 lakes throughout California during the spring and summer of 2012 and 2013. Almost one third of the bird samples had mercury levels in the blood that put them at an elevated risk of methylmercury toxicity (>1 ppm blood, wet weight, Ackerman et al. 2015).

Around Clear Lake, California, several species were monitored for effects of methylmercury exposure from the Sulphur Bank Mercury Mine. Ospreys (*Pandion haliaetus*) were found to have the highest concentrations of mercury in their feathers (20 mg/kg) compared to five other species that were sampled. The osprey reproduction appeared unaffected, producing 1.4 fledglings per nesting attempt (Cahill et al. 1998). Long term monitoring found average mercury concentrations in osprey feathers around Clear Lake varied from 20 mg/kg to 2 mg/kg and back up to 20 mg/kg over 14 years. Changes in the tropic structure of the aquatic food web may have caused the changes in mercury concentrations in osprey feathers, rather than efforts to clear up the Sulphur Bank Mercury Mine. Reproduction in osprey still appeared unimpaired by methylmercury, but the data was confounded by human disturbance (Anderson et al. 2008).

Mercury was monitored in 23 healthy adult Western and Clark's grebes (*Aechmophorus occidentalis* and *Aechmophorus clarkii*) collected at three study sites in California, in 1992: Clear Lake, Lake County; Eagle Lake, Lassen County; and Tule Lake, Siskiyou County (Elbert and Anderson 1998). Clear Lake birds ($n = 13$) had greater mercury concentrations in kidney, breast muscle, and brain than birds from the other two lakes ($p < 0.05$), whereas liver concentrations were not statistically different ($p > 0.05$). Mean brain tissue mercury levels were near, but below, those known to cause adverse effects. Brain mercury concentrations were also negatively correlated to blood potassium and blood phosphorus levels ($n = 11$, $p < 0.05$).

Kidney mercury levels were positively correlated to percent blood heterophils and negatively correlated to percent eosinophils ($n = 13$, $p < 0.05$), suggesting that mercury levels might be affecting immune function. However, these biomarkers could not be related to an effect to the population, such as a reduction in survival.

*J.2.3 Outside of California*

Severely reduced reproductive success was observed in loons in northwestern Ontario. The loons fed on fish with average concentrations of mercury between 0.3-0.4 mg/kg (wet weight). This was not a controlled feeding experiment, so the data was not used to derive a reference dose, but 0.3 mg/kg is referred to in the peer reviewed literature as a threshold for birds (Barr 1986).

The Carolina wren (*Thryothorus ludovicianus*) has been used as a model system of mercury effects on songbirds (see section on song sparrows in the San Francisco Bay area above). Jackson et al. found that nesting success (i.e., the ability to fledge at least one offspring) decreased as the parents mercury exposure increased, with a 10% or more nest failure when females had blood mercury of 0.7 ppm, 20% failure at blood mercury of 1.2 ppm and 30% failure at blood mercury of 1.7 ppm (Jackson et al. 2011). Other insectivorous songbirds and bats, particularly those associated with wetland habitats, have been shown to have elevated mercury (Edmonds et al. 2010, Evers et al. 2012).

Impacts to reproduction were observed in another captive model songbird species, the zebra finch (*Taeniopygia guttata*). The finches diet was dosed with 0.3 – 2.4 mg/kg methylmercury (Varian-Ramos et al. 2014). All doses of methylmercury reduced reproductive success, with the lowest dose reducing the number of independent offspring produced in one year by 16% and the highest dose, representing approximately half the lethal dose for this species, causing a 50% reduction in offspring. Birds were exposed to methylmercury either as adults only or throughout their lives. Birds exposed throughout their lives seem to develop some methylmercury tolerance since effects on birds exposed only as adults were more severe. The resulting concentrations of mercury in the blood ranged from about 4 to 33 ppm, which is higher than the concentrations at which Jackson et al. found effects in the Carolina wren (Jackson et al. 2011).

Songbirds from a mercury-contaminated site sang simpler, shorter songs in a lower tone compared to birds from other areas (Hallinger et al. 2010). Songs are important to finding mates and guarding territory. Swallows in the same mercury-contaminated areas laid about as many eggs as uncontaminated birds, and the eggs hatched, but many of the young died within the first week outside the egg. As a result, swallows in the contaminated area produced fewer fledglings than those in reference areas. Female swallows in the contaminated site had significantly elevated blood and feather total mercury (blood: 3.56 +/- 2.41 ppm wet weight vs. 0.17 +/- 0.15 ppm reference; feather: 13.55 +/- 6.94 mg/kg vs. 2.34 +/- 0.87 mg/kg reference), possibly the highest ever reported for an insectivorous songbird (Brasso and Cristol 2008).

Methylmercury has been found to impair the ability of birds to fly. The diets of captive starlings (*Sturnus vulgaris*) were dosed with methylmercury cysteine at 0.0, 0.75, or 1.5 mg/kg wet weight. Impaired flight can have a direct impact on survival during predation events or by decreased efficiency in other critical activities (such as foraging or migration) that require efficient flight (Carlson et al. 2014).

Although both bald eagles and osprey are large piscivorous birds that experience elevated mercury exposure in some environments, these species have not been well studied with respect to potential effects of methylmercury on reproductive success or other population parameters. Of the few existing published reports, most indicate a lack of association between methylmercury exposure and productivity of free-living eagles or osprey in different locations in the Great Lakes region (Bowerman et al. 1994), James Bay and the Hudson Bay area (DesGranges et al. 1998) and British Columbia (Weech et al. 2006). This is similar to the lack of effect in California osprey discussed previously (Cahill et al. 1998, Anderson et al. 2008.) Eagles in Chesapeake Bay are also thought to have lower risk. This conclusion is based on low concentrations of methylmercury in their feathers (Cristol et al. 2012). Meanwhile, in New York and Maine, feather mercury concentrations were about 10 times higher than in the Great Lakes region (DeSorbo et al. 2008, DeSorbo et al. 2009), which may be high enough to cause adverse effects based on the results of Evers et al., who found sublethal effects in loons at 40 mg/kg mercury in the feathers (Evers et al. 2008b). Other researchers have shown that eagles may experience subclinical neurological damage in the Great Lakes Region (Rutkiewicz et al. 2011).

### *J.2.4 Reviews of Effects on Loons*

Recent studies in the common loon have made them one of the most well studied species in regards to the effects of methylmercury in birds. Common loons are widely distributed geographically and long lived. They feed preferentially on small fish (100–150 mm in size) from lakes within established territories (Depew et al. 2012). Several thresholds for loon were derived by compiling information from many studies, as described below.

Burgess and Meyer measured mercury concentrations in small fish, blood mercury levels in adult male, female and juvenile common loons, lake pH, and loon productivity from 120 lakes in Wisconsin, USA and New Brunswick and Nova Scotia, Canada (Burgess and Meyer 2008). The fish sampled for the study were small fish (76–127 mm in length) typically consumed as prey by loons (supported by Barr 1996). Quantile regression analysis of the data set indicated that maximum observed loon productivity dropped 50% when fish mercury levels were 0.21 mg/kg (wet weight), and failed completely when fish mercury concentrations were 0.41 mg/kg. The authors did not determine a no effect threshold. However, the authors explain that this threshold is not appropriate for deriving regulatory thresholds: “The relationships between measures of loon mercury exposure and reproduction presented in this paper are correlative. Empirical dose–response studies will further define toxicity thresholds” (Burgess and Meyer 2008).

In another subsequent study on loons, screening benchmarks for use in ecological risk assessment were derived (Depew et al. 2012b). The results from Burgess and Meyer 2008 were incorporated into Depew et al. benchmarks, which were derived from a larger compilation of toxicity data. The lowest screening benchmark derived was 0.1 mg/kg (fish tissue, wet weight) for adult behavioral abnormalities, which was the midpoint of range for adverse adult behavior lowest effect level (0.05 - 0.15 mg/kg). The significant reproductive impairment threshold was 0.18 mg/kg, which included impacts to productivity and hatch success. The third threshold was for reproductive failure: 0.40 mg/kg.

Evers et al., used nearly 5,500 loon mercury measurements over an 18-year period to derive risk thresholds using the common loon (Evers et al. 2008b). The authors derived three risk categories for interpretive purposes based on mercury concentrations in blood: (1) low (<1.0 ppm), (2) moderate (1.0–3.0 ppm), and (3) high (>3.0 ppm). The risk categories were defined based on two thresholds for mercury measurements: (1) a low-exposure reference group, in which blood mercury level were all below were 1.0 ppm and (2) the authors found that 3.0 ppm in blood had a significant negative adverse effect on reproductive success. The authors used the benchmark that defined the threshold for the high risk category of 3 ppm mercury in blood as the adverse effects threshold. The authors do not assert the 3 ppm threshold or the 1 ppm threshold should be a protective criterion for loon (Evers et al. 2008b), although it was clear that a protective criterion should be no higher than 3 ppm in blood.

## J.3 Exposure and Effects in Mammals

The effects of methylmercury bioaccumulation on mammalian wildlife have been the focus of only a few investigations. Piscivorous mammals include mink, otter, seals, sea lions, bears (although black bears in California do not regularly eat fish), raccoons, water shrew, and muskrat. Much of the research on mammalian wildlife has looked at the global impact of elevated mercury by focusing on polar bears (Basu et al. 2009, Dietz et al. 2011) and whales (Lemes 2011).

In California, a few studies have measured mercury in seals and sea lions. Juvenile and adult harbor seals (*Phoca vitulina*) that feed in the open San Francisco Bay had blood mercury concentrations averaging slightly over 0.3 ppm in samples from 2003 to 2005 (Brookens et al. 2007). The significance of these concentrations is unclear because effects thresholds have not yet been determined. Evidence in stranded California sea lions suggests that high mercury exposure may make seals more susceptible to the algal toxin domoic acid. Stranded California sea lions (*Zalophus californianus*) with suspected domoic acid poisoning had significantly higher liver mercury concentrations when compared to animals classified with infectious disease or traumatic mortality (Harper et al. 2007).

## J.4 Exposure and Effects in Fish

The effects of methylmercury on fish species have recently been reviewed for freshwater habitats (Crump and Trudeau 2009; Sandheinrich and Wiener 2011). A great deal of evidence suggests that methylmercury in the aquatic environment impacts the reproductive health of fish (Crump and Trudeau 2009). Sandheinrich and Wiener reviewed about 20 studies of methylmercury's effect on survival and growth, behavior, reproduction, and changes in biochemical markers in fish. The authors concluded that sublethal effects of methylmercury on freshwater fish, including changes in reproductive health, occur at concentrations of 0.3-0.7 mg/kg wet weight or greater in the whole body and about 0.5-1.2 mg/kg or greater in the muscle tissue (Sandheinrich and Wiener 2011).

A whole-body mercury tissue threshold-effect level of 0.2 mg/kg wet weight (the corresponding muscle concentration would be higher) has been derived, based largely on sublethal endpoints (growth, reproduction, development, behavior) to protect juvenile and adult fish (Beckvar et al. 2005). Ten papers on eight fish species from the peer reviewed literature met the author's quality control criteria and were used to calculate the threshold. This level of mercury (0.2 mg/kg) is in the range commonly reported for top predator fish in California (see Staff Report, Section 4.5: Current Mercury Levels in the Environment), so methylmercury may be impairing reproduction in fish in California.

Depew et al. reviewed literature on toxic effects of methylmercury to fish and derived a *dietary* threshold for fish. Thresholds were about 0.05 mg/kg (wet weight) for reproductive and biochemical effects, 0.5 mg/kg for behavioral effects, 1.4 mg/kg for growth inhibition and 2.8 mg/kg for lethality (Depew et al. 2012a). These thresholds can be compared to the water quality objectives in the Provisions. To protect the top predator fish (trophic level 4 fish), mercury concentrations in prey fish (trophic level 3 fish) should meet the lowest threshold (0.05 mg/kg).

## J.5 Suggested Thresholds from the Literature

Tables J-1 and J-2 summarize suggested thresholds mainly from the peer reviewed literature. These data are compiled for comparison to the water quality objectives to protect wildlife in the Provisions (see Appendix K, Section K.7 for comparison), so only concentrations in fish tissue are included. Suggested thresholds in blood, feathers or eggs are not included in the tables because such thresholds are not easily comparable to the water quality objectives in the Provisions. Note that many of the tabulated thresholds are relevant to the *prey* of the species studied, which is generally lower trophic level fish and crustaceans, and not larger fish at the top of the food chain such as a large bass. Tables J-1 and J-2 include thresholds from controlled laboratory experiments and field studies. The field studies are described in the previous sections, while the controlled laboratory studies are described in the following paragraphs.

**Table J-1. Suggested dietary methylmercury thresholds from peer reviewed literature that that are most relevant to prey fish (including shellfish), unless otherwise noted.**

| Reference | Species; Effect(s) | Threshold in whole prey fish (mg/kg, wet weight) |
|---|---|---|
| Basu et al. 2007 | Mink; decreases in *N*-methyl-D-aspartic acid (NMDA) receptor (involved in learning and memory) | 0.1 (lowest effect level) |
| Barr et al. 1986 | Loon; reduced reproductive success | 0.3 (lowest effect level) |
| Burgess & Meyer 2008 | Loon: reproduction | 0.21 (50% drop in productivity) |
| Burgess & Meyer 2008 | Loon: reproduction | 0.41 (reproductive failure) |
| Carlson et al. 2014 | Starling; ability to fly (starling eat insects and fruit) | 0.75 (starling eat insects and fruit) |
| Depew et al. 2012b | Loon; adverse behavioral impacts | 0.1 (screening benchmark) |
| Depew et al. 2012b | Loon; significant reproductive impairment | 0.18 (screening benchmark) |
| Depew et al. 2012b | Loon; reproductive failure | 0.4 (screening benchmark) |
| Kenow et al. 2007, Kenow 2010 | Common loon; behavior changes | 0.08 (no effect level) |
| Kenow et al. 2007, Kenow 2010 | Common loon; behavior changes | 0.4 (lowest effect level) |
| Frederick and Jayasena 2010 | White ibis; reproductive and behavior changes (ibis eat mostly invertebrates and some fish) | 0.05-0.3 (lowest effect level) |
| Varian-Ramos et al. 2014 | Zebra finch; reduced reproductive success (finches eat seeds and plants) | 0.3 (lowest effect level) |

Effects on common loon chicks were observed after dosing them daily from hatch through day 105 with fish diets that contained control, 0.08, 0.4, or 1.2 mg/kg wet weight as methylmercury chloride. No overt signs of toxicity or significant reductions in growth or food-consumption rates were observed in any dose group, but there was evidence of reduced immune response in chicks that received ecologically relevant doses of methylmercury (0.4 mg/kg diet, wet weight, Kenow et al. 2007). Behavioral changes were also found in the loon chicks that received this same dose. Chicks were less likely to right themselves after being positioned on their backs during outdoor trials (0.4 mg/kg diet, wet weight, Kenow et al. 2010)

**Table J-2. Suggested methylmercury thresholds for fish tissue from peer reviewed literature that are relevant to all finfish.**

| Reference | Species; Effect(s) | Threshold in whole fish (mg/kg, wet weight) | Threshold in fish fillet (mg/kg, wet weight)* |
|---|---|---|---|
| Sandheinrich and Wiener 2011 | Fish, multiple species; reproduction | 0.3-0.7 | 0.5-1.2 |
| Depew et al. 2012a | Fish (dietary); reproductive and biochemical | 0.05 | 0.07 |
| Beckvar et al. 2005 | Fish, multiple species; growth reproduction, development, behavior | 0.2 | 0.3 |

*Calculated with equations from Peterson et al. 2007.

Juvenile captive white ibises (*Eudocimus albus*) were exposed to dietary methylmercury at three doses of 0.05, 0 1, or 0.3 mg/kg (wet weight) over 3 years, and their foraging behavior and efficiency (Adams and Frederick 2008 ), survival (Frederick et al. 2011), and breeding behavior (Frederick and Jayasena 2010) were examined. No negative effects on survival or foraging were observed (Adams and Frederick 2008, Frederick et al. 2011). The dietary methylmercury LOAEL (Lowest Observed Adverse Effect Level) value for a breeding behavior in white ibises exposed was 0.05 mg/kg (wet weight). The effects at the lowest doses (0.05 mg/kg) were increases in male–male pairing behavior, dose-related reductions in key courtship behaviors for males-female paring. Also, females exposed to 0.05 mg/kg fledged 34 % fewer young per female than control females, but the difference was not statically significant (Frederick and Jayasena 2010).

In mink (*Mustela vison*), dietary methylmercury exposure resulted in concentration-dependent decreases in N-methyl-D-aspartic acid (NMDA) receptors (involved in learning and memory) in the brain of wild and captive mink in Canada (Basu et al. 2007). Effects were seen in concentrations as low as 0.1 mg/kg. This concentration is close to the protective target of 0.077 mg/kg derived for mink (Appendix K).

Semi-domesticated female mink were fed daily diets containing 0.1, 0.5, and 1.0 mg/kg of total methylmercury (Dansereau et al. 1999). Piscivorous and non-piscivorous fish naturally contaminated with methylmercury were used to prepare the diets. Diets containing 0.1 mg/kg and 0.5 mg/kg were not lethal to first generation and second generation females for an exposure period of up to 704 days. Authors report that methylmercury exposure did not influence the survival and growth of neonatal kits. However, the proportion of females giving birth was low for all groups, except for the first generation females fed the 0.1 mg/kg diet. It was not clear if this effect was from methylmercury because there was not a lower exposure concentration (or control group) for comparison.

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