RESPONSE TO WORKING GROUP AND PUBLIC COMMENTS ON THE SITE C CLEAN ENERGY PROJECT ENVIRONMENTAL IMPACT STATEMENT

Technical Memo

METHYLMERCURY

MAY 8, 2013

REVISION 1 – JULY 19, 2013

Subject: Mercury

Purpose

A number of comments have been received during the Comment Period regarding the potential for the Project to change the bioaccumulation of methyl-mercury in environmental receptors, and to affect human health. The purpose of this technical memo is 1) to provide a summary of the relevant background technical information on mercury and reservoirs, including potential changes resulting from the creation of Site C reservoir, 2) to summarize conclusion of studies and human health risk analyses in support of the environmental assessment, 3) to introduce supplemental information, a wildlife risk assessment, that was requested by regulatory agencies because of concerns with potential wildlife and mercury interactions; and 4) supply additional information on mitigation details.

The information discussed in this technical memo was derived from the following EIS sections and technical appendices:

- EIS Section 11.9 Methylmercury
- EIS Section 33 Human Health
- Mercury Technical Synthesis Report (Part 1 of Volume 2 Appendix J, Mercury Technical Synthesis Report)
- Human Health Risk Assessment of Methylmercury in Fish (Part 2 of Volume 2 Appendix J, Human Health Risk Assessment of Methylmercury in Fish)
- Reservoir Modelling Report (Part 3 of Volume 2 Appendix J, Mercury Reservoir Modelling)

Methylmercury Technical Synthesis

This section on methylmercury briefly describes the 1) background information to understand mercury issues; 2) existing baseline levels of methylmercury in various environmental media in the technical study area; and 3) the approach and predictions of the changes in methylmercury levels for the environmental assessment.

Methylmercury and Reservoir Creation

Total mercury in the environment is the sum of all chemical forms of mercury including the inorganic or organic forms, primarily methylmercury. Both forms of mercury occur naturally in the environment, and their concentrations vary according to the media (e.g., water, sediment, aquatic insects, fish). Methyl-mercury is the chemical form of mercury that bioaccumulates in the food chain needs to be considered in reservoir creation. The typical percentage of methylmercury detected in total mercury in various environmental media is as follows:

- In vegetation and soil, methylmercury makes up less than 2% of total mercury
- In water, methylmercury usually comprises less than 5% of the total mercury
- In vegetation and soil, methylmercury makes up less than 2% of the total Mercury measured
- In benthic invertebrates, methylmercury comprises 30 – 50% of total mercury

- In fish, nearly all of the measured mercury is present as methylmercury[1]

Under natural conditions, mercury is present in low concentrations in all environmental media including water, soil, sediment, and plants, and in all terrestrial and aquatic animals. As noted above, methylmercury occurs in far lower concentration than does inorganic mercury in all environmental media except fish. In soils, water, and sediment, inorganic mercury is the prevalent form and originates from atmospheric (natural or anthropogenic) and geologic sources. Over time, inorganic mercury captured from the atmosphere by vegetation and accumulates, being sequestered and concentrated into terrestrial soils. Under these conditions, the natural rate of mercury methylation is low. However, when soils are flooded, degradation of the organic material creates favourable and accelerated conditions for sulphate-reducing bacteria that transform or “methylate” some of the inorganic mercury into organic mercury, primarily methylmercury. The rate of bacterial activity and mercury methylation is governed by many chemical factors such as the amount and quality of organic carbon, pH, and sulphate, not necessarily the amount of inorganic Mercury available.

Methylmercury is much more easily absorbed and accumulated by animals than inorganic mercury. Once methylmercury is incorporated by bacterial tissue, it becomes part of the food chain. Methylmercury accumulates at a greater rate than it degrades or is eliminated, accumulating over time within an organism (i.e., bioaccumulation), and becoming more concentrated through successive trophic levels (i.e., biomagnification). Thus, methylmercury concentrations are higher in large-bodied, longer-living animals, especially those at the top of the food chain such as predatory fish[2].

Flooding of terrestrial soil and vegetation to form new reservoirs creates conditions favourable for accelerating methylation rates. The degree to which this happens and how long these conditions persist varies among reservoirs. The rate and magnitude of methylmercury production is affected by many factors, and the response to inundation and reservoir creation differs among reservoirs. Reservoir-specific differences in these factors are responsible for the substantial variability in the number of years for fish to reach peak mercury concentrations, the magnitude of those peaks, and the return time to pre-flooding conditions that has been observed among reservoirs[3,4]. Data from Canadian reservoirs show general pattern of changes in fish mercury concentration over time. Mercury in adults of large, predatory species increases rapidly, with peak concentrations three to eight years after impoundment, after which levels decline to reach pre-impoundment (or baseline) concentrations within 15 to 25 years[5].

Fish-eating species (e.g., lake trout, bull trout) have the highest peak mercury concentrations, take the longest to reach maximum levels, and take longer to return to a baseline level, although there is

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1 Bloom, N.S. 1992. On the chemical form of mercury in edible fish and marine invertebrate tissue. Canadian Journal of Fisheries and Aquatic Sciences. 49: 1010-1017.

2 Bodaly, R.A, Hecky, R.E., and Fudge, R.J.P. 1984. Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. Canadian Journal of Fisheries and Aquatic Sciences 41: 682-691.

3 Bodaly, R. A., Jansen, W.A., Majewski, A.R., Fudge, R.J.P., Strange, N.E., Derksen, A.J., and D.J., and Green, A. 2007. Post-impoundment time course of increased mercury concentrations in fish in hydroelectric reservoirs of northern Manitoba, Canada. Arch. Environ. Contam. Toxicol. 53: 379-389.

4 Schetagne, R., J. Therrien and R. Lalumiere. 2003. Environmental monitoring at the La Grande complex. Evolution of fish mercury levels. Summary report 1978-2000. Direction Barrages et Environnement, Hydro-Québec Production and Groupe conseil GENIVAR Inc., 185 pp. and Appendices.

5 Munthe, J., Bodaly, R.A., Branfireun, B.A., Driscoll, C.T., Gilmour, C.C., Harris, R. Horvat, M., Lucotte, M., and Malm, O. 2007. Recovery of mercury-contaminated fisheries. Ambio 36: 33-44.

variability in each of these endpoints[6]. These differences are related to many reservoir-specific conditions, especially water residence time, ratio of reservoir area to original wetted area, organic carbon in soils, water pH, amount of flooded wetland, and food web complexity. The physical, chemical, and ecological factors that contribute to this are explored in detail within the Canadian reservoirs comparison matrix of the Mercury Technical Synthesis Report in the EIS Volume 2 Appendix J Mercury Technical Reports, Part 1.

Baseline Levels of Mercury in the Project Area

Both terrestrial (soils and vegetation) and aquatic environments (water, sediment, invertebrates and fish) within the Peace River study area were sampled to provide a basis for determining how the Site C Project will alter methylmercury concentration. The focus of these technical studies was on fish as they are the top predators in aquatic food chains and they are the environmental media for which the potential for bioaccumulation is greatest.

Mercury concentrations in terrestrial soils and vegetation, inventories or the mass of mercury and carbon in these environmental media are important drivers of mercury methylation. The most important component is the uppermost organic layer represented by the litter, fermentation, and humus horizons, within several centimetres (<5 cm) of the surface. Total mercury concentration in all plant tissues in the study area was low, in most cases just above the laboratory detection limit. Methylmercury was not measured, as methylmercury comprises a very low proportion (<2%) of total mercury concentration in plants. The average total mercury concentration of all organic soils within the upper 5 cm within the area forecast to be inundated by the Site C reservoir was found to be low.

Key parameters in the aquatic environment that influence generation and bioaccumulation of methylmercury are hydrology, limnology, and specific water and sediment chemistry parameters. In the Peace River technical study area, exclusive of high TSS events during freshet, total mercury concentration seldom exceeded 1 parts per trillion. The low total mercury concentration is a reflection of low levels of mercury found in water discharged from Williston Reservoir. Similarly low concentrations were measured from Williston Reservoir in the early 2000s[7] and these data suggest that conditions have not changed over the last nearly 15 years.

Methylmercury concentration in Peace River and tributary stream water was consistently below the laboratory detection limit in nearly all samples. The only exceptions occurred during in samples from the Moberly River and Halfway River during a high flow and high sediment load event. Total mercury concentration in sediment along the Peace River was either below the laboratory detection limits or in low concentrations when detectable.

The zooplankton total mercury concentrations are within the low range for plankton from remote lakes unaffected by anthropogenic or natural sources of mercury. These concentrations are comparable to or slightly lower than concentrations observed in reservoirs studies elsewhere in Canada, including La

[6] Footnote 3 and 4.

[7] Baker, R.F., R.R. Turner and D. Gass. 2002. Mercury in environmental media of Finlay Reach, Williston Reservoir, 2000 – 2001 data summary. A report prepared by EVS Environment Consultants, North Vancouver for BC Hydro Burnaby BC. March 2002.

Grande, Quebec[8] , Manitoba[9] and Finland[10]. Methylmercury form various taxonomic groups of benthos was low with methylmercury concentrations ranging from 20 – 37% of the total mercury.These concentrations are similar or lower than studies elsewhere in Canadian rivers and lower than other reservoirs.

Fish tissue mercury analysis has mainly focused on the dominant food web species observed in Dinosaur Reservoir, and downstream to the Site C dam site including bull trout, lake trout, Arctic grayling, burbot, lake whitefish, mountain whitefish, rainbow trout, longnose sucker, and redside shiner. Mercury concentration data have also been collected from fish species found downstream of Site C, as far downstream as Many Islands (northern pike, walleye, goldeye, burbot) and those whose habitat extends into Alberta. Mean mercury concentrations of all fish species in the Peace River between the Peace Canyon Dam and the Site C dam were less than 0.10 part per million, with concentrations in nearly all fish less than 0.20 parts per million. These are low concentrations, especially for the large piscivorous species like bull trout and lake trout. These concentrations are lower than for the same species of a similar size in all other B.C. lakes and reservoirs for which there are mercury data[11] and among the lowest in Canada[12].

Predictions of Future Methylmercury Levels

Several methods or lines of evidence were used to determine the most likely magnitude of change in methylmercury concentrations in environmental media resulting from the creation of the Site C reservoir. The three predictive tools were integrated together to derive a single, most likely estimate of change. The three tools employed and results include:

- Harris-Hutchinson regression model – This is a linear regression model that uses simple input parameters including original and flooded area (ha) and hydraulic residence time (or flow) to predict the relative degree to which fish mercury concentrations will increase and peak, relative to baseline values. Fish mercury concentrations in the Site C reservoir were predicted to increase by 2.3 time above baseline at peak levels. The model does not provide information regarding the timing of the peak concentration, nor the duration of elevated fish mercury concentrations.
- RESMERC – is a complex, quantitative, mechanistic model that includes the latest understanding from scientific studies on methylmercury dynamics in aquatic systems. RESMERC mimics the production, destruction, and bioaccumulation of MeHg in various environmental media in reservoirs

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8 Tremblay, A., M. Lucotte and R. Schetagne. 1998. Total mercury and methylmercury accumulation in zooplankton of hydroelectric reservoirs in northern Québec (Canada). The Science of the Total Environment 213 307-315.

9 Jackson, T. A. 1988b. Accumulation of mercury by plankton and benthic invertebrates in riverine lakes of northern Manitoba (Canada): importance of regionally and seasonally varying environmental factors. Canadian Journal of Fisheries and Aquatic Sciences 45: 1744-1757.

10 Sarkka, J. 1979. Mercury and chlorinated hydrocarbons in zooplankton of Lake Paijanne, Finland. Archives of Environmental Contamination and Toxicology 8:161–173.

11 Rieberger, K. 1992. Metal concentrations in fish tissue from uncontaminated B.C. lakes. B.C. Water Management Division, Water Quality Branch Ministry of Environment Lands and Parks, B.C. August 1992.

12 Depew, D., N.M. Burgess, M.R. Anderson, R.F. Baker, P.B. Satyendra, R.A. Bodaly, C.S. Eckley, M.S. Evans, N. Gantner, J.A. Graydon, K. Jacobs, J.E. LeBlanc, V.L. St. Louis and L.M. Campbell. 2012. An overview of mercury (Hg) concentrations in freshwater fish species: A national Hg fish data set for Canada. Canadian Journal of Fisheries and Aquatic Sciences. Accepted.

using mass balance calculations over time. The key outputs of this model are predictions of Hg and MeHg concentrations in water and biota (e.g., invertebrates, insects, fish) at any point in time, in this case, within the Site C reservoir. Fish mercury concentrations are predicted to increase by up to 4 to 6 times above baseline at peak levels, depending on the species, five to eight years after impoundment. Following the peak, fish mercury concentrations are expected to decline to baseline levels over a 15 to >20-year period. The magnitude and duration of elevated mercury concentrations depends on fish species and fish size. Larger, older fish will achieve higher concentrations.

- Canadian Reservoirs Comparison Matrix – a comprehensive review of many key physical, chemical, and ecological factors that are associated with creating conditions that enhance mercury methylation in reservoirs. Fifteen large reservoirs from Manitoba, Quebec, B.C. and Labrador were evaluated. Baseline and predicted values for these parameters from the Site C technical study area were contrasted against what has been observed elsewhere in Canada, to put the Project in perspective with other large Canadian hydroelectric projects, with a focus on changes in fish Hg concentrations over time. Fish mercury concentrations are predicted to increase by less than three times baseline concentrations, based on a large suite of physical, chemical, and ecological features assessed from 15 Canadian reservoirs.

A wildlife risk assessment was undertaken to assess the implications to wildlife of incrementally higher exposure to dietary methylmercury as a result of the proposed Site C reservoir. The wildlife risk assessment was conducted in accordance to provincial and federal guidance on ecological risk assessment.

Baseline methylmercury concentrations for all environmental media (water, sediment, invertebrates, fish) in It was conservatively assumed that the general fish population downstream of the Site C reservoir would double in concentration for key species (presented in the EIS Section 11.9 Table 11.9.4), this would result in mean mercury concentration for local populations of less than 0.10 part per million. The only exception is bull trout, with a mean of 0.16 parts per million. Despite this increase, these are very low concentrations relative to other fish populations in B.C[13] and elsewhere in Canada[14].

The timing of a return of reservoir fish mercury concentrations to baseline can also be inferred from the Canadian reservoirs comparison matrix as well as from RESMERC. Given the above two estimates, a return to baseline is likely closer to 20 years after impoundment than >25, because of the weight of evidence presented by the Canadian reservoirs comparison matrix and the presence of a large, oligotrophic, low-mercury Williston reservoir upstream that will continue to dominate water chemistry in a post-Project environment.

With respect to downstream fish, the return to baseline is much shorter. For example, lake whitefish in the Caniapisco River in northern Quebec returned to background levels within two to four years, while concentrations in lake trout remained high for four to eight years[15]. Downstream of the Smallwood Reservoir in Labrador, fish mercury concentrations had returned to baseline within seven to eight years after impoundment. Based on the weight of evidence from other Canadian reservoirs and the presence of a large, oligotrophic upstream reservoir, the return to baseline mercury concentrations in the

[13] Footnote 7.

[14] Footnote 12.

[15] Schetagne, R. and R. Verdon. 1999b. Post-impoundment evolution of fish mercury levels at the La Grande Complex, Quebec, Canada (from 1978 to 1996). In M. Lucotte, R. Schetagne, N. Thérien, C. Langlois, and A. Tremblay (eds.). Mercury in the Biogeochemical Cycle. Springer-Verlag, Berlin. 235–258.

downstream area is predicted to be, approximately four to six years after impoundment of the Site C dam.

Human Health Risk Assessment

A human health risk assessment was conducted for the Project to assess the changes in methylmercury levels in fish and potential effects to fish consumers. The human health risk assessment focuses on fish consumption by receptor type and activity (for recreation, subsistence and traditional use purposes) from water bodies where changes in methylmercury in fish could potentially occur as a result of the Project. This section summarizes the findings of the human health risk assessment.

All Canadians are exposed to methylmercury in their environment and the greatest source of exposure to methylmercury comes from eating fish. To protect consumers from an excess of dietary methylmercury, Health Canada has defined a ‘provisional tolerable daily intake’ or pTDI for methylmercury. The pTDI is the amount of methylmercury that a person can ingest without risk of adverse health effects. All fish contain methylmercury, with higher concentrations found in large, longer-lived predatory species such as bull trout and lake trout. Methylmercury exposure depends on how frequently fish are consumed, the serving size, species, age and size of fish consumed. Risk is also relative to the age and gender of the consumer because the developing nervous system of a child is more susceptible to the effects of methylmercury than that of an adult.

While methylmercury concentrations in fish would temporarily increase within the proposed Site C reservoir, the potential health risks associated with Methylmercury exposure from fish consumption needs to be carefully weighed against the health benefits of fish consumption. Baseline fish methylmercury concentrations in the technical study area are sufficiently low that, even during the period of peak post-inundation mercury levels, the fish consumption rate recommended by Health Canada’s Food Guide for Healthy Eating of two servings of fish a week could be met by consuming popular species of fish, such as rainbow trout, from the Site C reservoir without exceeding Health Canada’s pTDI for methylmercury.

The most commonly consumed type of freshwater fish reported by participants in the BC First Nations Food, Nutrition, and Environment Study and First Nations communities in closest proximity to the Project, and participants in the Duncan and Horse Lake First Nation’s Country Food Harvest Consumption Survey, was ‘trout’. Although not specifically broken down, the most commonly consumed species of trout are rainbow trout, bull trout and lake trout. Bull trout are emphasized in the HHRA because, of all trout species in the technical project area, bull trout have the highest current baseline mercury concentration.

As discussed below, follow-up monitoring of methylmercury will be conducted to verify model predictions for the environmental media (e.g. water, invertebrates, fish) into Alberta and confirm levels of methylmercury in fish consumed by recreation, subsistence and traditional purposes users.

Wildlife Risk Assessment

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Baseline methylmercury concentrations for all environmental media (water, sediment,invertebrates, fish) in the Peace River are amongst the lowest in Canada. It is well known that inundation of organic soils to create new reservoirs favors conditions that exacerbate the natural conversion of inorganic mercury into methylmercury. Methylmercury is easily absorbed by all aquatic organisms and concentrations at progressively higher concentrations in the aquatic food web, with highest concentrations in predatory fish. While the magnitude methylmercury concentrations associated with Project are expected to be much lower than what has been seen in eastern Canadian reservoirs, the general pattern of fish tissues peaking between five and 10 years before declining to near-baseline concentrations after 20 to 25 years, is expected to be similar.

This wildlife risk assessment targeted six mammal, seven bird and one amphibian species (collectively called receptors of concern). The species chosen are representative of those receptors of concern that are most likely to be exposed to methylmercury and include top predatory species such as northern river otter, American mink, bald eagle, and belted kingfisher. It also included one species at risk listed species, the western toad. The selection of the WRA receptor of concern was based on the following criteria:

- Presence of the species in the area and suitable habitat based on predictions regarding post-flooding habitat suitability made by project wildlife experts
- Reliance on the future reservoir for feeding (e.g., aquatic or emergent insects, or fish) or drinking
- Representation of the various feeding guilds likely present (e.g., herbivore, piscivore, omnivore)
- Social, economic, or cultural importance (e.g., species of importance to First Nations, species of commercial or recreational importance, listed species under provincial or federal legislation, etc.)

Toxicological literature was used to establish the relationship between dietary methylmercury exposure and adverse effects (e.g., to survival, growth and reproduction) for each receptors of concern group.

A food chain model was constructed and used to estimate the dose of methylmercury to each receptors of concern for each of four scenarios:

- Baseline (current conditions)
- Site C – Peak (highest one-year average fish methylmercury)
- Site C – Peak Average (highest 8-year average fish methylmercury)
- Site C – Long Term (future conditions after reservoir has stabilized)

These scenarios provide information to assess potential changes in key endpoints for each receptors of concern associated with the Project relative to current conditions. A key element was the use of RESMERC, a sophisticated mechanistic model that has the ability to predict methylmercury concentrations in a wide range of environmental media at any point in time following reservoir creation.

Predicted doses were then compared to the dose-response information to estimate potential effects of methylmercury exposure for the receptors of concern for each of the three Site C scenarios, relative to the baseline scenario. Key results were as follows:

- *Amphibians* – Predicted changes to effects endpoints for the western toad were negligible[16] for all Site C scenarios
- *Birds* – Predicted changes to effects endpoints for avian receptors of concern were negligible to low for all Site C scenarios. Among the seven species considered, belted kingfisher had the highest estimated exposure to methylmercury. Predicted doses for beleted kingfisher under the Site C – while Peak and Peak Average scenarios were sufficient to potentially reduce offspring production (by approximately 10 to 20%). Based on the life-history characteristics of the belted kingfisher, the predicted changes to offspring production were considered unlikely to result in changes at the population level. This is corroborated by comparisons of predicted fish tissue methylmercury concentrations to recently published tissue-based benchmarks for the protection of loons, a known sensitive species. Predicted changes for the other bird species considered in the assessment were negligible for the Site C – Peak and Peak Average scenarios. Long term changes for all receptors of concern were predicted to be negligible relative to baseline conditions.
- *Mammals* – Predicted changes to effects endpoints for all mammal receptors of concern were negligible for all Site C scenarios

In summary, notwithstanding exposure by receptors of concern to higher methylmercury doses compared to baseline conditions, predicted peak fish mercury concentrations in a post-Project environment are comparable to those seen in many remote and uncontaminated lakes in BC and are lower than most other Canadian lakes.

Details of the wildlife risk assessment can be seen in the attached document – Effects of Methylmercury on Wildlife.

Mitigation

As a key dimension of mitigation, a monitoring program will be implemented to monitor mercury levels in commonly consumed fish species to identify any changes in mercury concentrations. Below is a summary description of the proposed methyl-mercury monitoring framework including: 1) parameters; 2) locations; 3) time period; and 4) results and public communication.

Monitoring Parameters

Total and dissolved total mercury and total methylmercury from the surface water column within the lower reach of the proposed Site C reservoir will be monitored. Sampling will be stratified between the epilimnion and hypolimnion during mid to late summer, when the reservoir is predicted to be vertically thermally stratified. The frequency of water sampling will be monthly during the open water season as ice conditions permit safe access for sampling during winter.

Sport fish species as well as key food chain species will be targeted for monitoring both within the proposed reservoir and downstream. The species mix targeted from both areas may be different because of the transition from a lotic to a lentic environment within the proposed Site C reservoir. This lotic environment may support different fish species than in the downstream riverine environment. Key species targeted within the proposed reservoir are the sport species bull trout and rainbow trout and the food web species longnose sucker and redside shiner. These species are predicted to be the most

16 Within a risk assessment context, magnitude of predicted response (i.e., 'change') is often characterized as 'negligible' when the response is <10% and 'low' when 11 – 20%.

successful in the new reservoir during intermediate term (the first 10 to 15 years of reservoir operation) while the phenomenon of elevated mercury in environmental media is predicted to persist (Volume 2 Appendix J Mercury Technical Data Reports Part 1 Mercury Technical Synthesis Report).

Downstream of the proposed Site C dam site, the same species as above will be targeted as well as walleye and goldeye. These two species are more common downstream of the proposed dam site location and have been documented to move upstream from Alberta to the vicinity of Moberly River.

In addition to fish, in order to fully understand the movement and accumulation of methylmercury through the aquatic food web, methylmercury concentrations in lower trophic level biota both within the reservoir and the Peace River downstream will be monitored. A subsample of benthic invertebrates from the above monitoring locations collected as part of the ecosystem change monitoring program will be submitted for chemical analysis.

The key parameters to be monitored in all fish tissue samples are total mercury and stable carbon and nitrogen isotopes. The majority of mercury in fish tissue is in the form of methylmercury. Benthic invertebrate tissue samples will be measured for both inorganic and methylmercury as well as stable carbon and nitrogen isotopes. Stable isotopes are measured to determine the food web structure and dietary changes of fish that may occur after reservoir creation and will assist with interpreting possible changes in mercury concentrations in fish.

Monitoring Locations

Key monitoring locations will be identified within the proposed Site C reservoir, upstream within Dinosaur Reservoir and at strategic locations downstream of the proposed Site C dam site. The spatial extent of monitoring will extend as far downstream as the Smoky River in Alberta (the furthest downstream location that the most important sports species, bull trout, rainbow trout and possibly walleye may move from to access fish entrained or passed out of the Site C reservoir).

The following five sampling locations are proposed:

- Dinosaur Reservoir upstream of Peace Canyon dam
- Middle reach of Site C reservoir downstream of Halfway River
- Lower reach of Site C reservoir upstream of dam site
- Peace River below Taylor Bridge, upstream of Kiskatinaw River
- Peace River upstream of Smoky River, Alberta

Monitoring Time Period

Following inundation of soils to form the reservoir it may take one to two years before increased bacterial methylmercury production in newly flooded sediment may be accumulated and magnified through the aquatic food web and manifest within the tissue of predatory fish. Surveys for fish tissue mercury concentrations have typically been undertaken every three to five years in routine monitoring programs in new and existing reservoirs. This is due to a time lag between bacterial production and accumulation by fish and because the precision of surveys to detect significant changes over brief periods of time is relatively low. There is no precedent or prescribed timetable for monitoring of fish mercury concentrations in key species in new reservoirs and every situation may be different. In the specific case of the Site C, because baseline fish mercury concentrations are low (e.g., approximately 0.10 mg/kg), an increase of 20% would be difficult to distinguish from natural variability.

The RESMERC model provides a modeled response to predicted changes in fish mercury concentrations over time within the proposed Site C reservoir. The proposed monitoring program is based on this predicted temporal response with the proposed monitoring conducted during the following time periods or years based on construction (i.e., during diversion of the Peace River and partial inundation) and operations (i.e., immediately following complete inundation and full reservoir level):

Construction phase

- the first year following diversion and partial flooding
- two years later, just prior to full inundation

Operations phase

- the first full operating year following inundation
- three years following inundation
- six years following inundation – this also corresponds to the predicted maximum fish mercury concentration in predatory fish
- ten years following inundation
- every five years thereafter until such time as fish mercury concentrations have stabilized at a new ‘baseline’ concentration. This is predicted to be approximately 25 years after full inundation.

In addition to monitoring of fish mercury concentrations, a seasonal water quality monitoring program for mercury and methylmercury from multiple locations within the Site C reservoir, Dinosaur Reservoir upstream and downstream of Site C is proposed. Seasonal water quality data related to mercury will assist in tracking change in mercury in environmental media over time as the Site C reservoir evolves.

~~The timing of monitoring is related to the timing of Project related activities, including the ‘construction’ phase when the Peace River is constricted, directed through a diversion tunnel and there is some inundation of terrestrial soils upstream. Several years may be required for fish tissue mercury concentrations to change as they transition from baseline to peak before slowly returning to baseline. Following are timelines for collection of mercury and methylmercury in environmental media (water, invertebrates, fish):~~

- ~~Construction year 0, immediately after closure of the Peace River to document construction-related changes in mercury in environmental media~~
- ~~Construction year 2 (1 to 2 years before the Peace River is constricted)~~
- ~~Operation year 3, to determine the magnitude of change in mercury in environmental media during the early operation period~~

- ~~Operations year 6 near what is expected to be peak mercury concentrations in fish~~
- ~~Operations year 10 and every five years thereafter (i.e., operations year 15, Operations year 20, etc.)~~

This monitoring schedule will document temporal trends in changes to mercury and methylmercury concentrations in environmental media within the Site C reservoir and the Peace River downstream. This information will be used to confirm predictions made by the mercury modeling reports (Volume 2 Appendix J Part 3 Mercury Reservoir Modeling) and Section 11.9 Methylmercury.

Monitoring Results and Public Communication

If changes in mercury concentrations are higher than predicted, a human health risk analysis may be required (depending on actual mercury concentrations) to determine if changed mercury concentrations were to the level that would necessitate a fish consumption advisory to avoid exceedance of pTDI of mercury. If monitoring and risk analysis results indicate a potential health risk related consumption of fish obtained from the LAA, information will be provided to responsible regulatory authorities for supporting fish consumption advisories. This information will therefore assist in communications to the public and First Nations of the potential risk of methylmercury exposure at certain consumption levels of certain fish species for certain population groups. The advisories will also include information on the nutritional benefits of fish consumption, and types of fish that should be avoided or suggested. Any consumption advisories will be designed and implemented in accordance with federal and provincial procedures for issuing fish consumption advisories (Environment Canada, B.C. Ministry of Lands Natural Resource Operations, B.C. Ministry of Health) and in accordance with good practice, including:

- Communications that are culturally appropriate to Aboriginal groups (including translation into local Aboriginal languages where required)
- Supporting a collaborative methylmercury monitoring process with Aboriginal and other communities (e.g. communities providing tissue samples; participation in data collection and analysis)
- Mechanisms to solicit and respond to comments and questions from local communities on fish consumption advisory information

Conclusions

1. Baseline levels of methyl-mercury in environmental media in the Project area are generally low. Concentrations in water are consistently below detection limits in water. Concentrations in zooplankton are in the low category for remote lakes unaffected by anthropogenic influence and comparable or lower than concentrations in zooplankton in other reservoirs observed in studies across Canada. Concentrations in fish are lower than the same or comparable spepcies in all other lakes and reservoirs in BC and amongst the lowest observed in Canada.
2. Estimates of the increase in methyl mercury in the general community of fish associated with the creation of the Site C reservoir suggest that peak concentrations would increase by a factor of 3-4 times baseline levels, and return to baseline levels after approximately 20 years. Downstream fish community concentrations are predicted to increase by a factor of 2 time baselines levels, and return to baseline in four to six years.

3. The magnitude of predicted changes in methyl-mercury in environmental media that would result from the creation of the Site C reservoir are sufficiently low that, even during the period of peak post-inundation mercury levels will not create risks to fish, wildlife or human health.
4. As a result of the technical uncertainty associated with the prediction of changes in methyl-mercury, a follow up program is proposed to verify assessment of changes, and to assist in communicating results to the public and Aboriginal groups.

Related Comments / Information Requests:

This technical memo provides information related to the following Information Requests:

gov_0004-036	gov_0006-001	gov_0006-008	gov_0006-026	gov_0006-030
gov_0006-033	gov_0006-046	gov_0010-875	gov_0012-012	gov_0016_009
gov_0017-005	gov_0018_001	pub_0223-007	pub_0223-011	pub_0241-006
pub_0244-001	pub_0252-001	pub_0376-001	pub_0380-002	pub_0476-002
pub_0498-001	pub_0701-001	pub_0861-001	ab_0001-193	ab_0001-406
ab_0001-410	ab_0001-669	ab_0001-713	ab_0003-022	ab_0003-254
ab_0008-003	ab_0009-002	ab_0010-015	ab_0010-024	ab_0010-025
ab_0010-131	ab_0010-132	ab_0010-160	ab_0001-533	ab_0001-535

Response to Working Group and Public Comments on the Site C Clean Energy Project Environmental Impact Statement

Technical Memo – Attachment 1

METHYLMERCURY

MAY 8, 2013

SITE C CLEAN ENERGY PROJECT

Effects of Methylmercury on Wildlife

April 2013

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SITE C CLEAN ENERGY PROJECT

Technical Data Report:

Wildlife Risk Assessment

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EXECUTIVE SUMMARY

This Wildlife Risk Assessment (WRA) was undertaken to assess the implications to wildlife of incrementally higher exposure to dietary methylmercury as a result of construction and operation of the proposed Site C Clean Energy Project. This WRA conforms to provincial and federal guidance on ecological risk assessment.

Baseline methylmercury concentrations for key environmental media (e.g., water, sediment, invertebrates and fish) in the Peace River are amongst the lowest in Canada. It is well known that inundation of organic soils to create new reservoirs favors conditions that exacerbate the natural conversion of inorganic mercury into methylmercury. Methylmercury is easily absorbed by aquatic organisms and occurs at progressively higher concentrations up the aquatic food chain, with highest concentrations in predatory fish. While the magnitude of methylmercury concentrations associated with Site C are expected to be much lower than what has been seen in eastern Canadian reservoirs, the general pattern (i.e., methylmercury concentrations in fish tissues peaking between 5 and 10 years before declining to near-baseline concentrations after 20 to 25 years) is expected to be similar.

This WRA targeted six mammal, seven bird and one amphibian species (collectively called receptors of concern [ROCs]). The species chosen are representative of those ROCs that are most likely to be exposed to methylmercury and include top predatory species (e.g., northern river otter, American mink, bald eagle, and belted kingfisher). They also included one species at risk, the western toad.

Toxicological literature was used to establish the relationship between dietary methylmercury exposure and adverse effects (e.g., to survival, growth and reproduction) for each ROC group.

A food chain model was constructed and used to estimate the dose of methylmercury to each ROC for each of four scenarios: 1) baseline (current conditions); 2) Site C – Peak (highest one-year average fish methylmercury); 3) Site C – Peak Average (highest 8-year average fish methylmercury); and 4) Site C – Long Term (future conditions after reservoir has stabilized). These scenarios provide information to assess potential changes in key endpoints for each ROC associated with Site C relative to current conditions. A key element was the use of RESMERC, a sophisticated mechanistic model that has the ability to predict methylmercury concentrations in a wide range of environmental media at any point in time following reservoir creation.

Predicted doses of methylmercury (mg/kg body weight/d) were then compared to the dose-response information to estimate potential effects[1] of methylmercury exposure for the ROCs for each of the three Site C scenarios, relative to the baseline scenario[2]. Key results were as follows:

- *Amphibians* – Predicted changes to effects endpoints for the western toad were negligible for all Site C scenarios.
- *Birds* – Predicted changes to effects endpoints for avian ROCs were negligible to low for all Site C scenarios. Among the seven species considered, belted kingfisher had the highest estimated exposure to methylmercury and predicted doses for the Site C – Peak and Peak Average scenarios were sufficient to potentially reduce offspring production (by approximately 10 to 20%); based on the life-history characteristics of the belted kingfisher, the predicted changes to offspring production were considered unlikely to result in changes at the population level. This is corroborated by comparisons of predicted fish tissue methylmercury concentrations to recently published tissue-based benchmarks for the protection of loons, a known sensitive species. Predicted changes for the other ROCs were generally negligible for the Site C – Peak and Peak Average scenarios. Long term changes for all ROCs were predicted to be negligible relative to baseline conditions.
- *Mammals* – Predicted changes to effects endpoints for all mammal ROCs were negligible for all Site C scenarios.

With respect to risk to wildlife feeding downstream of the Site C dam, Section 11.9 Methylmercury of the EIS predicts that the net increase in mercury in downstream fish is no more than half of what may be observed within Site C reservoir and will persist for a shorter time

[1] The percent reductions in effects endpoints reported herein should be considered a guide only; they represent our best guess based on the underlying dose-response data, but have moderate to high uncertainty.

[2] Within a risk assessment context, magnitude of predicted response (i.e., 'change') is often characterized as 'negligible' when the response is <10% and 'low' when 11 – 20%.

period. Consequently, risks to wildlife feeding on fish or biota entrained out of the reservoir are expected to be lower than risks to wildlife feeding within reservoir, as described above.

In summary, notwithstanding exposure by ROCs to higher methylmercury doses compared to baseline conditions, predicted peak fish mercury concentrations in a post-Site C environment are comparable to those seen in many remote and uncontaminated lakes in BC and are lower than most other Canadian lakes.

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AEL .... Adverse Effect Level

BAF .... Bioaccumulation Factor

BCMOE .... BC Ministry of the Environment

BCF .... Bioconcentration Factor

DOC .... dissolved organic carbon

dw .... dry weight

EIS .... Environmental Impact Statement

ERA .... Ecological Risk Assessment

g .... grams

Hg .... Mercury

HHRA .... Human Health Risk Assessment

HQ .... Hazard Quotient

LOE .... Line of Evidence

µg .... micrograms

ng .... nanograms

QA/QC .... Quality Assurance/Quality Control

RESMERC .... Reservoir Mercury Model

ROC .... Receptor of Concern

TRV .... Toxicity Reference Value

VBA .... Microsoft Visual Basic for Applications

VC .... Valued Component

WRA .... Wildlife Risk Assessment

ww .... wet weight

1.0 INTRODUCTION

This report presents a Wildlife Risk Assessment (WRA) to assess potential ecological risks associated with increased exposure to methylmercury by key wildlife species following construction of the Site C Clean Energy Project. Creation of a new reservoir will change methylmercury concentrations in environmental media and result in increased exposure of terrestrial animals to methylmercury. Similar to the human health risk assessment carried out for Site C (Volume 2, Appendix J, Part 2), this WRA addresses the potential incremental risk of exposure of methylmercury to insectivorous birds and fish-eating birds and mammals.

The approach used for this WRA was carried out in accordance with provincial and federal guidance on ecological risk assessment, as laid out by the BC Science Advisory Board (2008) and the Federal Contaminated Sites Action Plan (FCSAP 2012). This WRA was not undertaken as part of an environmental assessment of effects as part of the Environmental Impact Statement (EIS) for the Site C project.

1.1 BACKGROUND

This document has been prepared to support Site C Project environmental assessment. The Site C Project description can be found in the Site C EIS (CEAA website). Extensive baseline information and modelling future conditions has been conducted for the Site C Project. Detailed information on the dynamics of methylmercury in the environment and the influence of inundation of organic soils following reservoir creation can be found in:

- *Mercury Technical Reports,* Volume 2 Appendix J, Part 1, Mercury Technical Synthesis Report)
- *Mercury Technical Reports,* Volume 2 Appendix J, Part 2, Mercury Human Health Risk Assessment of Methylmercury in Fish)
- *Mercury Technical Reports,* Volume 2 Appendix J, Part 3, Mercury Reservoir Modeling (RESMERC)
- *Section 11.9 Methylmercury* of the Site C Clean Energy Project EIS

Other applicable documentation includes:

- EIS Section 12 Fish and Fish Habitat
- Appendix E Water Quality Baseline Conditions in the Peace River
- Appendix H Reservoir Water Temperature and Ice Regime Report
- Appendix P Aquatic Productivity Reports

1.2 OBJECTIVES AND APPROACH

The objectives of this WRA were to characterize potential risks of elevated methylmercury exposure associated with the proposed Site C Project to local wildlife species.

The approach used for this WRA was in accordance with provincial and federal guidance on ecological risk assessment (Science Advisory Board 2008; FCSAP 2012) and followed a two-step process:

- **Section 2** *Problem Formulation* – this section describes how reservoir creation will affect methylmercury concentrations in the aquatic environment, both within and downstream of the Site C reservoir, the selection of receptors of concern (ROCs) and key exposure pathways. Details are provided regarding the focus of the risk assessment and how its results will be interpreted.
- **Section 3** *Risk Assessment* – this section describes the methods (and results) for estimating methylmercury exposure for each ROC and for compiling toxicological data from literature sources to derive dose-response data sets for each ROC group (e.g., birds, mammals and amphibians). It also presents the integration of the exposure and effects assessments to estimate potential changes related to increased methylmercury exposure associated with Site C and discusses key uncertainties and their influence on the risk predictions.

Given the dynamic nature of expected changes in methylmercury concentrations associated with reservoir creation, four exposure scenarios were developed to provide a broad range of temporal context. The WRA relied on food chain modeling to quantify dietary methylmercury exposure for each ROC from water, sediment and food items. A key element of the exposure assessment was the use of RESMERC, a sophisticated mechanistic model, to predict methylmercury concentrations in water, sediment, lower trophic level biota and fish (output customized for the WRA) at any point in time during the evolution of changes to methylmercury concentrations in within the Site C reservoir (details provided in EIS Volume 2, Appendix J, Part 3, Mercury Reservoir Modeling). Risks were characterized by comparing predicted exposure to a compilation of toxicological data compiled from the literature.

2.0 PROBLEM FORMULATION

The elements of problem formulation included in this section are listed below:

- Site characterization and scenario identification
- Discussion of the environmental dynamics of mercury as they relate to hydroelectric reservoirs
- Identification of the receptors of concern relevant to the site, including any provincially and federally listed species (i.e., rare and endangered species)
- Analysis of exposure pathways and development of a conceptual model
- Discussion of protection goals and adverse effect levels (AELs)
- Identification of assessment and measurement endpoints, and lines of evidence (LOEs)

2.1 SITE CHARACTERIZATION AND SCENARIO IDENTIFICATION

2.1.1 Site Characterization – Expected Changes within the Reservoir

Following the creation of the Site C reservoir, the aquatic environment of the Peace River upstream of the dam to the tailrace of Peace Canyon Dam would undergo a dynamic ecosystem transformation. This aquatic environment would be transformed from a riverine environment with shallow depth, uniform distribution of temperature, oxygen and nutrients, to a more lake-like environment with horizontal and vertical changes to limnological conditions, productivity, habitat features and structure of the food web and fish species community (Appendix P Aquatic Productivity Reports). There would be an initial surge of sediment, nutrients and productivity in the newly flooded reservoir over the short term, diminishing over time as the reservoir reaches a new equilibrium. Predicted changes to fish habitat during this transformation is presented in the EIS Volume 2 Appendix P Aquatic Productivity Reports, and Part 3 Future Conditions in the Peace River. Changes in fish habitat are based on calculations that quantify conversions of lotic habitats in the existing Peace River and its tributaries to lacustrine habitats in the Site C reservoir, divided among a predicted 9.4 km^2 of littoral area and 83.6 km^2 of pelagic area. Net productivity of the reservoir over the long-term is expected to be similar to current day productivity, although the system will transform from a primarily periphyton driven community to a more pelagic, plankton driven community (Site C EIS Volume 2, Appendix P, Part 3).

It is also anticipated that most fish species currently residing in the Peace River and its tributaries within the reservoir inundation zone would be present in the Site C reservoir after inundation. However, the relative abundance and biomass of fish species within the reservoir fish community would change during transition from a river to a reservoir. The short-term (10 years), medium-term (10 to 25 years), and long-term fish communities (> 25 years) are summarized within Site C Environmental Impact Statement Volume 2: Section11.9. Note that from a fish mercury perspective, the timelines regarding the evolution of methylmercury in fish are different from the timelines for short, medium and long-term transition of the fish community within the Site C reservoir as purported in the EIS Section 12 Fish and Fish Habitat.

Following reservoir creation, methylmercury concentrations will increase in all environmental media, particularly fish. Based on information provided in the EIS Section 11.9, fish tissue mercury concentrations are expected to peak during the first few years after inundation (e.g., 5 to 8 years), followed by a gradual reduction to near-baseline conditions over the next 15 to 20 years. Again, piscivorous species will have the highest peak concentrations, take the longest to reach maximum levels, and take longer to return to a baseline level, although there is variability in each of these endpoints (Bodaly et al. 1984; 2007; Schetagne et al. 2003). Note that the timelines for increases in methylmercury concentration are different for the water column, sediment, lower trophic level biota (zooplankton, benthos) and lower trophic level fish. Predictions of the timelines of each of these media are presented in the Appendix 2 Volume J Part 3, Mercury Reservoir Modeling report (RESMERC).

This temporal change in methylmercury concentrations for a typical carnivorous fish species is illustrated in **Figure 2.1.1.** It shows the typical pattern of increase in body burden of methylmercury reflecting bioaccumulation of methylmercury over time in response to generation of methylmercury in the sediments. This pattern has been borne out in many studies (e.g., Bodaly et al. 2007; Schetagne et al. 2003).

2.1.2 Scenario Identification

Characterizing methylmercury-related risks to wildlife requires an understanding of baseline (i.e., current conditions in the absence of Site C) and predicted future (i.e., assuming developing of Site C) risks. As discussed in **Section 2.1.1**, the expected pattern of methylmercury concentrations in fish is expected to vary temporally following reservoir construction. Consequently, in addition to the baseline scenario, three future scenarios were selected to provide insights into risks for different time frames rather than focusing on a single case. The food chain model considers four scenarios; the scenarios are intended to cover the time span from pre-reservoir conditions to 40 years post construction when methylmercury concentrations are expected to be stable. The scenarios are defined as the following and illustrated in **Figure 2.1.2**:

- **Peace – Baseline** – Evaluates current (i.e., pre-reservoir) exposure conditions in the Peace River. The baseline scenario allows for the estimation of the incremental methylmercury-related risks to wildlife relative to pre-reservoir conditions.
- **Site C – Peak** – Evaluates the worst-case methylmercury concentrations (i.e., highest one-year average) within the Site C reservoir (post-construction). This scenario is intended to document the incremental risks for animals using the Site during worst-case concentrations.
- **Site C – Peak Average** – Evaluates the average concentrations occurring from years five to 12 as methylmercury concentrations begin to decrease from peak concentrations. This scenario is intended to document the incremental risks for animals after peak concentrations but prior to stabilization of methylmercury concentrations.
- **Site C – Long Term –** Evaluates average concentrations occurring during years 30 to 40[3] when methylmercury concentrations in the reservoir are expect to remain stable.

[3] RESMERC predictions for the timing of return to near-baseline methylmercury concentrations in fish is 20 to 25 or more years, depending on the species. However, based on the comparative assessment of physical, biological and chemical characteristics of the proposed Site C Project relative to other Canadian reservoirs, the EIS (Volume 2, Section 11.9 Methylmercury) concluded that it would be closer to 20 years.

This long term scenario is intended to document the incremental risks for animals after concentrations have stabilized.

2.2 ENVIRONMENTAL DYNAMICS OF MERCURY

The purpose of this section is to review the environmental dynamics of inorganic mercury and organic or methylmercury in the environment and how reservoir creation alters this balance and causes methylmercury concentrations to increase throughout the food web. Key concepts presented include a summary of factors that influence methylation of inorganic mercury, and the dynamics of bioaccumulation and biomagnification of methylmercury at different levels of the aquatic food web. A more complete discussion of the environmental dynamics of mercury is presented in Volume 2 Appendix J Part 1 Mercury Technical Synthesis report.

2.2.1 Mercury and Mercury Methylation

Under natural conditions, mercury is present in low concentrations in all environmental media including water, soil, sediment, plants and in all terrestrial and aquatic animals. The proportion of methylmercury relative to ‘total’ mercury is far lower in concentration in all environmental media except fish, where it is primarily methylmercury (95%; Bloom 1992). In soils, water and sediment, inorganic mercury is the prevalent form and originates from atmospheric (natural or anthropogenic) and geologic sources. When soils are flooded, degradation of organic material creates favorable conditions for sulfate-reducing bacteria that transform or “methylate” some of the inorganic mercury into organic mercury, primarily methylmercury (although there are other forms). The rate of bacterial activity and mercury methylation is governed by many factors (e.g., organic carbon, pH and sulphate) rather than simply the inorganic mercury concentration.

There are a large number of physical, chemical and ecological parameters that are either positively or negatively associated with increases in mercury methylation rates. These have been summarized within the Canadian reservoirs comparison matrix contained in Volume 2 Appendix J, Part 1 Mercury Technical Synthesis Report.

Among the large number of factors considered based on an extensive literature review, the most important physical factors associated with enhanced mercury methylation were:

- Total reservoir area – Larger reservoirs have fish with higher mercury concentrations and take longer to return to baseline or background (relative to nearby lakes)
- Ratio of total reservoir area (original area) – The higher the ratio, the greater amount of methylmercury that is generated
- Water residence time – Fish from longer residence time reservoirs have higher Hg concentrations that persist for a longer period

The most important chemical factors were:

- Slightly acidic pH (<6.5) water is associated with higher Hg concentrations in fish
- Higher total or dissolved organic carbon (TOC/DOC) concentrations in water (> 5 mg/L) are weakly but positively correlated with the magnitude of increase in fish Hg
- Labile or easily degradable carbon, best represented by the amount (% of total and/or hectares) of wetland within the reservoir has been found to be a key contributor to elevated mercury methylation rates.

The most important ecological factors are:

- Lower trophic level Hg concentration – Lakes / rivers with higher baseline methylmercury concentrations in benthos realize higher methylmercury increases post-flood and contribute to higher rates of bioaccumulation and biomagnification by fish.
- Reservoir productivity – Larger reservoirs with more in situ nutrients, and nutrient inputs from upstream and/ or tributaries have greater biomass production and higher Hg methylation potential, and consequently, higher methylmercury concentrations in biota.

When each of these factors were compared against the physical, chemical and ecological features forecast for the proposed Site C reservoir, none of the above parameters were associated with a strong positive influence on mercury methylation. Site C will have an upstream oligotrophic reservoir (Williston), low TOC and nutrients in water, alkaline pH, low temperature and high oxygen (i.e., primarily as a result of water received from Williston), small increase in reservoir area relative to original river area, small area of flooded wetland and short hydraulic residence time. These factors combined with low baseline methylmercury concentrations in water, invertebrates and fish do not favour large increases (i.e., >4x above baseline) in methylmercury within the new reservoir.

2.2.2 Bioaccumulation and Biomagnification

Methylmercury is much more easily absorbed and accumulated by animals than inorganic mercury. Once methylmercury is generated within the sediments by bacteria, it is incorporated within the bacterial tissue and is now integrated within the base of the food web and is easily accumulated at a greater rate within the body of all organisms than it degrades or is eliminated. Thus there is a net accumulation of methylmercury over time with tissue concentrations being much higher than background sediment or water concentrations (i.e., bioaccumulation).

The phenomenon of biomagnification refers to the process whereby methylmercury becomes increasingly concentrated at progressive steps up the trophic structure of the aquatic food web. In lakes, rivers and reservoirs that are at least 30 years old, there is a dynamic equilibrium that normally exists in the absence of an outside influence (e.g., atmospheric, point-source, logging, flooding) that may affect total input of inorganic mercury. In the absence of such factors, the ratio of total inorganic to methylmercury and the absolute concentration of methylmercury in biota is fairly constant. However, when an area is flooded, there is more methylmercury generated from the available pool of inorganic mercury that is reflected up the food web.

In most environmental media (except fish), the concentration of methylmercury is small and difficult to measure, except by a small number of specialized laboratories. The typical percentage of the total mercury that is comprised of methylmercury in various environmental media is as follows:

- In vegetation and soil, less than 2% of total mercury is methylmercury.
- In water, usually comprises less than 5% of the total mercury is methylmercury.
- In benthic invertebrates, between 30 – 50% of total mercury is methylmercury. This can differ substantially within taxa however, similar to fish. Herbivorous invertebrates will

have lower concentrations of methylmercury than omnivorous and carnivorous invertebrates, which have the highest concentrations, sometimes, similar to some fish.

- In fish, nearly all measured mercury is in the methylmercury form with highest concentrations in fish relative to all other media. Fish is by far the greatest source of methylmercury exposure to wildlife species.

Finally, the methylmercury concentration in fish can vary according to species, diet and fish size/age. Young, small bodied fish that feed on algae and invertebrates will have lower mercury concentrations than larger, older fish. Fish diet is a key element that dictates mercury concentration at all life history stages. Predatory fish that consume other fish (e.g., walleye, northern pike, lake trout, bull trout) will have higher mercury concentrations than fish that consume invertebrates (e.g., rainbow trout, whitefish) and/or algae and periphyton (e.g., suckers, minnows) (Potter et al. 1975; Abernathy and Cumbie 1977; Bodaly and Hecky 1979; Bodaly et al. 1984; Hall et al. 1997 and others).

2.2.3 Potential Downstream Effects

Monitoring programs for boreal reservoirs have demonstrated that mercury concentrations increased in some fish downstream of new reservoirs in Quebec (Schetagne and Verdon 1999a, 1999b), Manitoba (Bodaly et al. 2007) and Labrador (Anderson 2011). The extent and duration of downstream changes to fish Hg levels vary from system to system, depending on the hydrological and biological characteristics of the rivers and reservoirs.

The degree to which fish mercury concentrations may increase downstream of Site C was predicted within the EIS Section 11.9.4. Mercury may be exported from the Site C reservoir via water (i.e., inorganic Hg adhered to sediment particles or MeHg dissolved in water) or directly, in biota (e.g., tissue Hg in invertebrates or fish) through entrainment from the reservoir. While water-borne Hg may lead to low magnitude changes across a broad spatial extent the importance of this pathway was considered secondary relative to biota-related mercury exports, which may lead to higher magnitude changes in a more localized area, such as the tailrace area of a dam.

The degree to which mercury concentrations in individual fish may increase downstream of the Site C reservoir will also vary by species, fish size, the biomass and mercury concentration of fish entrained out of the reservoir, and the dietary preference of individual fish. Downstream of Site C, mercury concentration of normally non-piscivorous species is unlikely to change substantially relative to baseline. For normally piscivorous species feeding in the tailrace area, the magnitude of increase may match what is observed within Site C. For normally non-piscivorous species that switch to a predominantly fish-based diet, their tissue mercury concentrations may increase more than what is seen for the same species within the Site C reservoir.

From a population perspective however, only a small portion of fish may potentially be affected living in the Peace River downstream to Many Islands, Alberta. This is mainly because the mass of mercury contained within fish entrained out of Site C reservoir is not sufficient to result in a widespread increase in Hg in most fish, combined with the small number of fish within the greater population that may switch to a piscivorous diet. Changes of the magnitudes seen in other Canadian reservoirs would be limited largely to those few piscivorous fish feeding predominantly in the tailrace area. Nevertheless, if it is conservatively assumed that the general fish population downstream of the Site C reservoir was to double in concentration for key species relative to baseline, then concentrations would be at least half of what is predicted for within the Site C reservoir.

2.3 RECEPTORS OF CONCERN (ROCS)

In ecological risk assessment, specific individual organisms (e.g., individuals of listed species), populations or communities that are potentially exposed to contaminants of concern (methylmercury in this case) are defined as receptors of concern (ROCs)[4]. This WRA targets wildlife (birds, mammals, and amphibians). For practical reasons, not all wildlife species can be considered in a risk assessment, so surrogate, or representative, receptors were selected based on discussions with BC Hydro and Keystone Wildlife Research Ltd. (Keystone).

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[4] It is also possible to select communities or habitats as ROCs.

2.3.1 Selection Process

As BC Hydro has assessed effects to wildlife in the Site C EIS Volume 2, Section 14, Wildlife Resources, ROC selection for the WRA was determined in consultation with project wildlife biologists. Starting the master list of wildlife species, a subset of ROCs was selected for the WRA based on the following criteria:

(1) Presence of suitable habitat based on predictions regarding post-flooding habitat suitability made by wildlife experts

(2) Reliance on the future reservoir for feeding (e.g., aquatic or emergent insects, or fish) or drinking.

(3) Representation of the various feeding guilds likely present on the Site (e.g., herbivore, piscivore, omnivore)

(4) Social, economic, or cultural importance (e.g., species of importance to First Nations, species of commercial or recreational importance, listed species under provincial or federal legislation, etc.)

2.3.2 ROC Groups and Surrogates

The surrogate ROCs developed with BC Hydro and Keystone (**Table 2.3.1**) represent various receptor group (e.g. mammals, birds, amphibians) feeding guilds likely present on site and includes the American beaver (*Castor canadensis*), moose (*Alces alces*), muskrat (*Ondatra zibethicus*), northern river otter (*Lontra canadensis*), American mink (*Mustela vison*), little brown myotis (*Myotis lucifugus*), Canada goose (*Branta Canadensis*), mallard (*Anas platyrhynchos*), bank swallow (*Riparia riparia)*, spotted sandpiper (*Actitis macularia*), bald eagle (*Haliaeetus leucocephalus*), common merganser (*Mergus merganser*), belted kingfisher (*Megaceryle alcyon*), and the western toad (*Bufo boreas*). Western toad is the only species at risk in this WRA.

2.4 EXPOSURE PATHWAYS AND CONCEPTUAL MODEL

Exposure pathways are generally defined as the route of exposure from environmental media (soil, water, air, or aquatic sediment) to the ROCs. Depending on the site and the nature of the potential contaminant, there can be multiple open pathways that must be evaluated in terms of their potential risk to receptors. The key is to identify the pathways which are most likely to drive risk during the problem formulation stage, so that uncertainties with respect to those pathways can be addressed to the extent possible.

Contaminant effects on receptors can be direct or indirect. Direct effects are toxic effects to the organism that may arise from direct exposure to contaminated media, such as contact and absorption of contaminants in the water column, sediment, or soil, and ingestion of contaminated prey items. Indirect effects are effects that may arise from contaminant-related depletion or impairment of food sources or habitat, and are expected to be minimal for this site. Consequently, this WRA focused only on the direct effects of methylmercury on wildlife and from exposure to methylmercury in diet, which is the major pathway of exposure of biota (Hall et al. 1997).

It is important to note here that our assessment of effects is independent of all other potential changes that may occur directly or indrectly to the particular ROCs and/or their habitats. Creation of a large new reservoir from a river will considerably alter water quality (e.g., turbidity, temperature) and many other factors that could affect ROC populations including prey community composition and distribution, nesting habitat, access, and other habitat/prey dependent parameters that will confound any contaminant-related changes.

Table 2.4.1 summarizes the exposure pathways considered in the WRA and provides justifications for their inclusion or removal. Exposure pathways are only considered “open” and included if there is a route of exposure by which a ROC comes into contact with methylmercury.

Methylmercury concentrations for aquatic exposure media (e.g., sediment, water, fish, aquatic invertebrates, and plants) are expected to differ for the four different scenarios modelled (**Section 2.1.2; Appendix D** [RESMERC predictions]), while media concentrations for terrestrial pathways (e.g., soils, plants, small mammals, and birds) are expected to remain the same for current Peace River baseline and future (Site C) scenarios (see **Section 3.2** for the exposure assessment).

Several ROCs eat fish as large portion of their diet (greater than 30 percent), including the mink, northern river otter, bald eagle, belted kingfisher, and common merganser. Once the Site C reservoir is in place, the fish species composition is expected to change from existing conditions, within the short-term (less than five years post construction) and again within the medium to long-term (i.e., greater than 5 years and 20 years post construction). For example Section 11.9 (Methylmercury) and Section 12 (Fish and Fish Habitat) of the Site C EIS forecasts the most likely change in fish community in the short- to medium term (i.e., <10 years) during the period of time when exposure by ROCs to greatest methylmercury concentrations in fish is predicted to occur. Again, time frames discussed here are particular to the evolution of methylmercury concentration in fish, which are described more fully in Section 11.9 of the EIS.

- Top Predators (fish eaters) – Bull trout (*Salvelinus confluentus*) are currently the dominant top predator within the Peace River and are expected to remain dominant within the reservoir in the short-term (< 10 y), but may be replaced by a more lacustrine adapted species such as lake trout (*Salvelinus namaycush*) in the long-term (> 15y).
- Benthivores - Mountain whitefish (*Prosopium williamsoni)* are expected to decline immediately following reservoir formation. Lake whitefish (*Coregonus clupeaformis*) which are presently numerically scarce) may increase in the Site C reservoir, but not in the short term.
- Planktivores – Kokanee (*Oncorhynchus nerka*) are the only true planktivores that currently reside in the Peace River area, but are currently numerically scarce. A kokanee population may become established and eventually dominate the reservoir in the long term, but this is uncertain pending spawning and rearing habitat. They are not expected to dominate in the short-term during the period of highest mercury concentrations.
- Insectivores - Rainbow trout (*Oncorhynchus mykiss*) are expected to remain the dominant insectivore.

- Omnivores – Three sucker species currently reside in the Peace River area, longnose sucker (*Catostomus catostomus*), largescale sucker (*Catostomus macrocheilus*), and white sucker (*Catostomus commersoni*). The longnose sucker is predicted to be the dominant omnivore species in the Site C reservoir over the short-term (less than five years).
- Forage - Redside shiner (*Richardsonius balteatus*) are currently the numerically dominant forage fish species in the Site C area and are predicted to be the dominant forage species in the Site C reservoir.

For the purposes of this WRA, four fish species were chosen for model inclusion as representative fish species likely to compose the majority of wildlife fish dietary component based on the following criteria: 1) currently found in the Peace River within the future reservoir footprint; 2) expected to dominate the Site C reservoir in the short- to medium-term (less than ten years); and 3) represent major trophic levels expected to dominate the Site C reservoir. These include:

- Bull trout (top predator)
- Rainbow trout (insectivore)
- Longnose sucker (omnivore)
- Redside shiner (forage)

Planktivorous and benthivorous species were not included as they are not expected to be present within the new reservoir in numerically large numbers during the time frame when mercury is elevated. Once the majority of methylmercury has worked its way through the system, kokanee (*O. nerka*) are expected to be one of the numerically dominant species.

Dermal exposure and inhalation exposure pathways for methylmercury were not evaluated in this study, nor are they considered relevant. In British Columbia, there is currently no guidance on methods for assessing these pathways to ecological receptors and the *Tier 1 ERA Policy Decision Summary* (BC Ministry of Environment Lands and Parks 2000) excludes dermal and inhalation pathways for wildlife receptors.

To illustrate the relationship between the primary contamination sources, exposure pathways, and receptor groups, we developed a conceptual exposure model for the Site (**Figure 2.4.1**).

2.5 PROTECTION GOALS AND ACCEPTABLE EFFECTS LEVELS

Ecological risk assessment is a tool for decision-making, but ultimately, the acceptability of estimated risks and their associated uncertainty needs to be determined by the risk managers (Hope 2007). This means that frequent and clear communication is needed between risk assessors and risk managers to ensure that results of the risk assessment are understood and useful from a management perspective.

For most ecological risk assessments, results are more easily interpreted if there are clearly articulated protection goals and adverse effect levels (AELs):

- A protection goal is a narrative statement that defines the desirable level of protection for a receptor or receptor group.
- An AEL operationalizes the protection goal by specifying the magnitude or rate of effects that would be acceptable for a specific measurement endpoint or a group of measurement endpoints[5].

This information is meant to provide a basis for "judging" results of the risk assessment and deciding whether predicted impacts are acceptable. There is considerable latitude at the federal level for interpreting results of ecological risk assessment. While more guidance is currently available at the provincial level, it is primarily intended for handling contaminated sites rather than supporting environmental impact assessments.

For instance, under the British Columbia *Contaminated Sites Regulation*, it is BCMOE policy to use a 20 percent effect level as a benchmark for aquatic receptors (Science Advisory Board 2008), though a lower, negligible effect level (e.g., 10 percent) may be appropriate for listed species (this is general practice in British Columbia and is alluded to in Science Advisory Board

[5] Given the inter-linkages between AELs and endpoints, they are typically developed at the same time (see **Section 2.6**).

2008). For terrestrial environments, both federal and provincial regulations and guidance recognize that differing levels of ecological protection are afforded to different land uses, such as residential, commercial or agricultural. While these do not apply directly to Site C, they are informative of how other regulatory regimes are interpreting effect magnitude.

Overall, there are still many challenges when attempting to reconcile the use of AELs with an interpretation of acceptable or unacceptable ecological impacts:

- AEL benchmarks should not be used to generate oversimplified dichotomous categorizations – in reality, there is little difference between a 19 percent effect size and a 21 percent effect size, and our confidence in distinguishing such small differences will generally be very low.
- The implications of a specific AEL on any given measurement endpoint for a population or community will vary widely depending on whether the measurement endpoint applies directly to a population (e.g., abundance), community (e.g., species richness), or to individual organisms within a population (e.g., growth or fecundity).
- Derivation of ecologically meaningful AELs can be complex - there is not necessarily a "one size fits all" effect size – even among common wildlife species, different life history characteristics may require different effect sizes (e.g., *r* vs. *K* reproductive strategies: a specified AEL has different implications for a mouse than a moose).
- AELs apply to individual lines of evidence (LOEs), which do not get interpreted in isolation when multiple LOEs are investigated.
- Finally, while AELs are used to evaluate the magnitude of predicted impacts, risks also consider other factors such as the spatial extent of impacts and, most importantly, the evidence for causal linkages between the predicted effects and contaminant exposure estimates.

Given some of these challenges, the approach adopted for this WRA focuses on characterizing risks (or "changes" in the context of environmental impact assessment) and their associated uncertainties with all judgments of acceptability being made after the risk assessment is completed (FCSAP 2012).

2.6 ENDPOINTS AND LINES OF EVIDENCE

As shown in **Table 2.6.1**, the information presented in this section establishes the relationship between ROCs, assessment endpoints, measurement endpoints, and LOEs. This is a critical component of the problem formulation for the Site C Hydro Clean Energy Project as it lays out the foundation for developing the strategy and methods for the WRA. Key definitions are provided below (FCSAP 2012; Science Advisory Board 2008):

- ***Assessment Endpoints*** – An assessment endpoint is an explicit expression of the environmental value to be protected. An assessment endpoint is operationally defined by an ecological entity (e.g., individual organism, local population[6], specific community) and its attributes (e.g., abundance or diversity). The area for which the risk is estimated should also be defined (Suter et al. 2000; Suter et al. 2005). Implementation of the WRA should be sufficient to characterize risks at spatial scales that are: 1) ecologically meaningful; and 2) able to support risk management at a practical level of resolution. An ecological risk assessment may have one assessment endpoint per receptor group (particularly if the assessment endpoints are broadly worded) or multiple assessment endpoints per receptor group (if assessment endpoints are more specific).
- ***Measurement Endpoints*** – Measures of exposure for, or effects on, a receptor, or to measure changes in attributes of assessment endpoints. Ideally measurement endpoints directly represent the assessment endpoint attributes – for example, benthic community abundance or richness can be measured directly. However, in many cases measurement endpoints serve as indirect measures that require some extrapolation to make inferences regarding the status of the assessment endpoints – for example,

[6] The assessment population consists of a group of conspecific organisms occupying a defined area that has been selected to serve as an assessment endpoint entity for the ERA (Barnthouse et al 2008). The assessment population is operationally defined in this PF as the local population, which consists of all organisms exposed to, or indirectly affected by, contaminants originating from the Site.

effects on growth or reproduction of individual organisms in toxicity tests may need to be related to the assessment endpoint of population level attributes such as abundance or viability. While measurement endpoints may be formulated in various ways (see FCSAP 2012 and Science Advisory Board 2008), for this WRA the measurement endpoints are simple measures of exposure or effects, and the interpretation (e.g., comparison to benchmarks) occurs when the measurement endpoints are used in LOEs.

- ***LOEs*** – Pairings of exposure and effects measures provide evidence for the evaluation of a specific measurement endpoint. An LOE may have one or more measurement endpoints. In the case of this WRA (food chain model only), there is generally only one measurement endpoint (**Table 2.6.1**): comparison of estimated total dose (using a food chain model using) to a literature-derived dose-response dataset, to qualitatively determine the magnitude of potential risks. Other relevant information is discussed to help place the LOE results in context.

3.0 RISK ASSESSMENT

As described in **Table 2.6.1**, the assessment endpoint for wildlife species is the viability[7] of local populations[8] for common species; survival, reproduction, growth, and deformities of individual organisms[9] (for listed species).

This assessment endpoint was evaluated using one line of evidence (LOE 1) for each ROC - the comparison of an estimated total methylmercury dose (calculated from a food chain model using measured and predicted methylmercury concentrations in dietary items collected from the Site) to dose-response information from the literature relevant for effects on survival, reproduction, and growth. Other information is considered where appropriate to put the results of LOE 1 into context.

A total of 14 ROCs were evaluated (six mammals, seven birds and one amphibian; **Table 2.3.1**). The only species at risk among the ROCs is the western toad.

3.1 APPROACH

Methylmercury-related risks to wildlife ROCs were estimated for the four scenarios described in **Section 2.1.2**:

- Baseline Peace River
- Site C – Peak
- Site C – Peak Average
- Site C – Long Term

The scenarios differ largely on the basis of actual (baseline) or expected (Site C) methylmercury concentrations in environmental media.

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[7] We define viability as the ability of a population to sustain itself over the long term. We assume that assessing organism level attributes will be protective of population attributes.

[8] The assessment population consists of a group of conspecific organisms occupying a defined area that has been selected to serve as an assessment endpoint entity for the ERA (Barnthouse et al 2008). The assessment population is operationally defined in the ERA as the local population, which consists of all organisms exposed to, or indirectly affected by, contaminants at the Site.

[9] The measurement endpoint is based on an average individual within a test population.

Risk is characterized (**Section 3.4**) for each ROC/scenario combination by comparing the exposure estimate (**Section 3.2**) to the corresponding dose-response profile (derived from literature sources) for methylmercury from (**Section 3.3**). Key uncertainties, and their influence on the risk predictions, are discussed in **Section 3.5**.

3.2 EXPOSURE ASSESSMENT

This section presents the methods for and results of predicting methylmercury doses for each ROC. In general, methylmercury intake (i.e., daily dose) for each ROC for each of the four scenarios was estimated using a food chain model that includes contributions to methylmercury intake from all relevant exposure pathways (i.e., consumption of food items and water, as well as the incidental ingestion of sediments and soils).

3.2.1 Food Chain Model - Methods

Modeling calculations followed provincial guidance for Tier 1 ecological risk assessment at contaminated sites (BCMOE 1998) and for detailed ecological risk assessment (Science Advisory Board 2008; FCSAP 2012). The food chain model was constructed using Microsoft Visual Basic for Applications (VBA) in Microsoft Excel (see **Section B1 in Appendix B** for model equations). Multiple Excel worksheets were used to organize model input parameters. All calculations (e.g., dose calculations, comparisons to benchmarks doses) were run in VBA, and model results were output to Excel worksheets.

To quantify exposure for each ROC, the following input parameters were required for the food chain model:

1. Exposure concentrations – measured or estimated methylmercury concentrations in prey, water, soil, and sediment were needed for each scenario. These are summarized in **Table 3.2.1** (see **Section B2.1 in Appendices B and D** for details).
2. Ingestion rates – measured or estimated ingestion rates for food, water, soil, and sediment were needed for each ROC. These were obtained from key secondary and primary literature sources and are summarized in **Table 3.2.2** (see **Section B2.2 in Appendix B** for details).

3. Dietary preferences – dietary uptake of methylmercury is typically the most important exposure route for wildlife ROCs, and especially from fish. Secondary and primary literature sources where used to characterize the diet of each ROC. The results are summarized in **Table 3.2.3** (see **Section B2.3 in Appendix B** for details).

4. Foraging range – this parameter can be important for sites significantly smaller than a ROCs foraging range. In the case of Site C (a large site), we conservatively assumed that the ROCs were feeding exclusively within the development footprint and immediately adjacent terrestrial habitats (for ROCs with diets including terrestrial items).

5. Methylmercury bioavailability (i.e., absorption efficiency in the gut) – while metals bioavailability can vary substantially across media and sites (e.g., due to chemical form present), methylmercury is generally considered highly bioavailable when ingested by wildlife. Wiener et al. (2007) reported that fish probably assimilate from 65 to 80% or more of methylmercury present in the food they eat. While no direct estimates of bioavailability were available for wildlife species, we conservatively assumed for each ROC that 100% of ingested methylmercury was assimilated.

Given the complexity of the food chain model, several QA/QC procedures were followed to verify its accuracy:

- Preparation and review of model checklists to ensure that:
  - All data sources were included, and assumptions were properly represented.
  - ROC-specific parameters were correct and updated.
  - Calculations and units were correct.
- QA/QC check of all model input worksheets (e.g., diet concentrations, ingestion rates) by a separate Azimuth ERA practitioner.
- A subset of the analyses was run independently outside of the VBA framework (i.e., using traditional Excel formulae) as a quality control check. Five of the ROCs (mink, mallard, Canada goose, belted kingfisher and northern river otter) were modeled using

Excel for each of the four scenarios. Essentially this provided two independent models: VBA and Excel versions, to cross-check results. The QA/QC check for the model calculations was only considered acceptable if the resulting estimates of total dose agreed exactly to several decimal places.

3.2.2 Food Chain Model - Results

Detailed food chain model outputs and QA/QC check results are presented in **Appendix C** and summarized in **Table 3.2.4**. Among ROCs, the highest estimated doses occurs for the belted kingfisher and the northern river otter under the Site C – Peak scenario – 0.041 mg/kg-day (wet weight) for the belted kingfisher and 0.013 mg/kg-day for the northern river otter; for both ROCs the source of methylmercury in the diet was 98% or more from fish. These doses are the focus for risk characterization as they represent worst-case modeled exposure. If these doses result in acceptable risks, all other doses (i.e., for other ROCs and scenarios) would also be acceptable.

3.3 EFFECTS ASSESSMENT

The term 'effects assessment' is a standardly used term in risk assessment and is not intended to represent effects *per se* as would be undertaken within the context of an EIS. The aim of effects assessment is to characterize the relationship between exposure (via dose) and effects. Typically, practitioners use point-estimate Toxicity Reference Values (TRVs) that have been derived from literature studies linking responses to exposure dose. Published TRVs are available for use in ERA. Some of the more commonly used include ORNL's toxicological benchmarks for wildlife (Sample et al., 1996) and, more recently, the USEPA's ecological soil screening levels (Eco-SSLs) documents. In both cases, the reported TRVs focus on defining no-observed-adverse-effects-levels (NOAELs) and/or lowest-observed-adverse-effects-levels (LOAELs). These designations are typically determined based on statistical significance either within individual laboratory studies (ORNL) or among toxicity datasets (Eco-SSLs). While these studies are accepted as a default under current BCMOE policy (Technical Guidance 7), the estimated NOAELs and LOAELs are strongly influenced by study design and, by themselves, do not provide information about the actual magnitude of effects associated with the TRV (or with the exceedence of a TRV). In fact, they are no longer considered appropriate for use in wildlife risk assessments by the scientific community (Landis and Chapman 2011). Allard et al. (2010) recently made a number of recommendations for the derivation and use of TRVs and options for moving beyond published TRVs. Given the disadvantages and uncertainties related to the use of published point estimate TRVs, they recommended that risk assessors compile available data and try to understand underlying dose-response relationships.

Following these recommendations, the effects assessment for the Site C Clean Energy Project is based on explicit use of the dose-response data.

3.3.1 Dose-Response Data – Methods

Following recommendations of Allard et al. (2010) and Hill et al. (submitted), we compiled separate data sets for birds, mammals and amphibians and only considered endpoints related to survival, reproduction or growth – other endpoints (e.g., enzyme activity) that cannot be easily related to potential impacts were not considered. The criteria used for data selection are presented and discussed in **Appendix E** (birds) and **Appendix F** (mammals); few studies were available for amphibians, so the results are presented in **Section 3.3.2**.

3.3.2 Dose-Response Data – Results

Methylmercury dose-response data sets for birds and mammals are presented in **Appendices E** and **F**, respectively.

Amphibian related dose-response toxicological data for methylmercury are limited and only one study (Unrine et al. 2004) was evaluated for relevant endpoints related to survival, growth and reproduction. Unrine et al. (2004) conducted a spiked mesocosm study using southern leopard frog larvae (*Rana sphenocephala)* exposed to a mercury-contaminated *aufwuchs*[10] diet throughout the entire larval period (days 60 to 254). Endpoints investigated in the study included mortality, metamorphic success rate, malformation, and changes to growth and development. Four dietary test concentrations were included in the study (control, low, medium and high); 14, 110, 366, and 858 mg total mercury/kg diet wet weight. These concentrations corresponded to

[10] *Aufwuchs* was defined as the accumulation of periphyton and associated organisms, as well as dead and abiotic material on submerged surfaces.

methylmercury concentrations of 3.1, 3.7, 6.9 and 12.9 mg methylmercury/kg diet wet weight (assuming 22, 3.4, 1.9 and 1.5% methylmercury, respectively). Corresponding effects were documented for all treatment concentrations. For comparison to the oral doses calculated for the western toad in the Site C food chain model, oral doses were calculated from the test concentrations presented in Unrine et al. (2004) using an average feeding rate of 180 mg/day (Unrine and Jagoe 2004) and an average body weight of 4.6 g (Lillywhite 1973). The calculated oral doses and effects data from Unrine et al. (2004) are presented in **Table 3.3.1.**

3.4 Risk Characterization – Results and Discussion

Details related to risk characterization for bird and mammal ROCs are presented in **Appendices E** and **F**, respectively, and are summarized and discussed in **Sections 3.4.1** and **3.4.2**, respectively. Results for the western toad are presented and discussed in **Section 3.4.3**.

The intensity of information presented to place predicted risks into context is based on the need for context. Consequently, more risk characterization information was presented for birds than for mammals or amphibians because predicted doses for avian ROCs were within the lower end of the dose-response data set and warranted additional discussion.

3.4.1 Birds

As discussed above, this section presents the results of several complementary comparisons:

- Predicted doses to laboratory-based dose-response data
- Predicted doses to field-based dose-response data
- Predicted fish tissue concentrations to field-based tissue benchmarks
- Predicted fish tissue concentrations to fish from uncontaminated lakes in BC

Finally, where the above suggests potential effects for individual ROCs, the available information is integrated to estimate potential for changes to be observed at the population level.

Comparison of Predicted Doses to Laboratory-based Dose-Response Data

As discussed in **Section 3.2.2**, estimated doses of methylmercury (mg/kg bw/day) were highest for the belted kingfisher, more than double the next highest avian ROC (common merganser). When the maximum estimated dose (i.e., the Site C - Peak scenario) for the belted kingfisher is plotted against the dose-response data for birds (**Appendix E**), the dose is low enough that there is no indication of potential effects on survival or growth. However, results for reproduction qualitatively indicate a possible effects range of between 10% to 40% relative to a lab control for the Site C – Peak scenario (**Figure 3.4.1**). It is important to point out that the qualitative interpretation of potential effects to belted kingfisher reproduction for the Peace – Baseline scenario would only be marginally lower, despite prevailing low methylmercury concentrations in Peace River media (EIS Section 11.9). These results reflect the high uncertainty in the dose-response data for avian reproduction in the low dose ranges[11] (**Figure 3.4.1**).

Effects estimates were quantified to facilitate comparisons between ROCs and scenarios by fitting a generalized logistic function (see **Appendix E** for details) to the dose-response data; the resulting response predictions, relative to the Peace – Baseline scenario, are an approximation of reductions in offspring production for each ROC/Site C scenario combination (**Table 3.4.1**). The Site C – Peak Average scenario results show that most ROCs are predicted to have less than a 10% reduction in offspring production; the exception is the belted kingfisher, which is predicted to have a 15% drop in offspring production. The implications of this change in reproductive output at the population level are discussed later in this section. Predicted changes associated with the Site C - Long Term scenario are considered negligible for all other ROCs.

Comparison of Predicted Doses to Field-based Dose-Response Data

Field data for birds are also available related to reproduction (**Appendix E**) – though sparse and uncertain, field data for the common loon are not inconsistent with the lab data. The results of

[11] One of the main reasons for this is a single study on white ibis (Frederick and Jayasena 2011), which showed reduced fledgling production at dietary concentrations of 0.05, 0.1 and 0.3 mg methylmercury/kg ww compared to the study control over the three year exposure period. While the dose-response pattern was variable and lacked consistency across the three exposure treatments, the authors also reported a higher incidence of male-male pairing that could exacerbate the reproductive effects in the wild.

two field-based loon studies (Barr 1986 and Burgess and Meyer 2008) corroborate the potential for reduced offspring production at methylmercury doses estimated for the belted kingfisher in the two peak Site C scenarios.

Comparison of Predicted Fish Tissue Concentrations to Field-based Tissue Benchmarks

As a complementary analysis, we compared the predicted fish tissue concentrations of methylmercury for Site C with fish tissue concentration benchmarks (for 100 to 150 mm fish, near the target size; **Appendix D**) recently proposed to be protective of behavioural and reproductive effects in the loon (Depew et al. 2012): 0.1 mg/kg wet weight as a benchmark for behavioural effects, 0.18 mg/kg wet weight as a benchmark for significant reproductive impairment, and 0.40 mg/kg wet weight as a benchmark for complete reproductive failure. The predicted concentrations for Site C prey item mercury concentrations (0.09 mg/kg for Peak, 0.08 mg/kg for Peak Average and 0.03 mg/kg for Long Term; for fish < 120 mm) are below all these benchmarks, suggesting that effects on loon would not be expected.

Comparison of Predicted Site C Fish Tissue Concentrations to Uncontaminated Lakes in BC

Current baseline fish mercury concentrations within the Peace River are among the lowest for their species in Canada (Depew et al., 2013). To put Site C predicted fish mercury concentrations into perspective within BC, data from uncontaminated BC lakes were compiled from two data sources: Rieberger (1992) documents metals concentrations in fish collected from 54 lakes in BC collected between 1982 and 1987 by BC Ministry of Environment, and Baker (2002) compiled available fish mercury data sets in BC from reservoirs and lakes (no reservoirs and only data for lakes removed from anthropogenic input were included herein).

Given the general influence of fish size on mercury concentrations, direct comparison of the fish mercury concentrations used in the WRA would be misleading as they are for smaller fish than generally measured in the compile BC lake data. Consequently, the highest RESMERC results for fish sizes that most closely matched the mean size of the compiled BC data were used to provide a more meaningful comparison. The results for 10 species are shown in **Figure 3.4.2** (note: Rieberger triangles; Baker circles). The horizontal lines across the figure depict predicted peak mercury concentrations from RESMERC for 400-mm bull trout (BLTR; 0.34 mg/kg), 300-

mm rainbow trout (RNTR; 0.14 mg/kg), 300-mm mountain whitefish (MNWH; 0.13 mg/kg), 300 mm longnose sucker (LNSC; 0.10 mg/kg) and 100 mm redside shiner (RDSH; 0.12 mg/kg). The Site C peak concentrations are well within the range of what is considered 'background' from a large number of lakes scattered throughout the province of British Columbia. Again, the data depicted for most fish in **Figure 3.4.2** are for sizes that are generally larger than what typically would be targeted as a food source by most birds.

Weight-of-Evidence Assessment of Population-level Effects to Belted Kingfisher

Based on comparison of the food chain model results to laboratory-based dose-response data, estimated methylmercury doses for belted kingfisher in the Site C – Peak Average scenario were predicted to result in approximately 15% lower reproductive output relative to the Peak – Baseline scenario. While this is less than the 20% effect size commonly applied as the limit for acceptable change in ecological risk assessments in BC (see **Section 2.5** for discussion), the results were explored further to provide further clarity in the extrapolation of individual effects to the local belted kingfisher population.

Although the available information suggests no affects to growth or adult survival for any scenario; offspring production may be impaired over the 8-year period (**Figure 2.1.2**) when fish mercury concentrations are expected to peak in Site C (i.e., the Site C – Peak Average scenario), then are expected to return to near-normal levels some 15 to 20 years after the peak.

For example, Gleason and Nacci (2001) conducted age-structured population modeling to explore how reproductive stressors affected birds with different life-history strategies. The study included the European kingfisher (*Alcedo atthis*; with higher offspring production, higher adult morality and a shorter life span) and the least tern (*Sterna antillarum*; with lower offspring production, lower adult mortality and a longer life span). The study results provide several insights relevant to belted kingfisher at Site C, whose life history strategy is more similar to the European kingfisher than the least tern. First of all, an elasticity analysis – the comparison of the proportional change in population growth for each species from the same proportional change in each vital rate (i.e., survival or reproduction) – showed that adult survival was a more important contributor to population growth than reproduction for both species (although reproduction was more important for the European kingfisher than for the least tern), suggesting that some change to reproductive output could occur without adversely affecting the population. This result was similar to that found for Todiramphus kingfishers in the Pacific islands (Kesler and Haig 2007). Secondly, although they projected minor (<10%) changes to European kingfisher populations with the application of 10% reproductive impairment sustained for 20 years, approximately 40% and 65% reductions in populations were seen for the 15 and 20% impairment levels, respectively. While these results confirm that reproductive impairment of this magnitude can affect population size, these results cannot be directly applied to Site C as the methylmercury concentrations in fish associated with reservoir creation are not constant over time (see **Section 2.1.1**). Furthermore, as discussed above, there are a multitude of other factors that will potentially influence each ROC at the population level that are associated with the transition from a river to a reservoir and may confound the influence of greater exposure to methylmercury.

To explore the potential implications of temporally dynamic reproductive impairment on belted kingfishers at Site C, yearly population status was simulated using a simple density-independent population growth model (Nt = Ni*λt-I, where N is population size, t = end of year, i = beginning of year, and λ = projected population growth rate between time i and t). Assuming similar life histories between the European and belted kingfishers, the plotted relationship between population growth rate (λ) and reproductive impairment (%) for the European kingfisher from Gleason and Nacci (2001) was used to derive projected population growth rate estimates for the belted kingfisher for a range of effect sizes. RESMERC (Volume 2 Appendix J, Part 3) fish mercury results (e.g., **Figure 2.1.2**) were used to estimate annual reproductive impairment for the belted kingfisher for 50 years following reservoir creation; these were then matched to the closest population growth rates from Gleason and Nacci (2001). Starting with an initial population size of 100 birds (to facilitate interpretation of results, not to suggest a particular population size for Site C[1]), the predicted population size for Site C dropped as low as 87 in year 13 (i.e., just after the Site C – Peak Average period) and had fully recovered by year 20. These results indicate that exposure to elevated methylmercury concentrations at Site C, independent of other confounding variables, may result in a temporary reduction in the population size of belted kingfisher (assuming similar vital rates as the European kingfisher), but that full recovery would be expected.

The population modelling results are consistent with the previously discussed comparisons of estimated fish tissue methylmercury concentrations at Site C to published benchmarks for the protection of loons and to uncontaminated lakes in BC. Thus, we conclude that risks to belted kingfisher reproductive output are most likely to be 'negligible' relative to baseline conditions. There is moderate uncertainty in this conclusion because effects data are limited, and there are no data specifically for the belted kingfisher.

To put these results into perspective, habitat-related changes at Site C may be more important in affecting the dynamics of the local belted kingfisher population. Two key elements of habitat suitability for the belted kingfisher are: 1) availability of nesting sites and 2) water clarity. Belted kingfisher excavate nesting burrows in cut banks consisting of sandy clay, generally situated beyond 1 m from the bottom and top of the bank (Prose, 1985). Reservoir development will alter bank morphology, possibly limiting the availability (or at least stability) of these features at Site C. Belted kingfisher also require clear water to see their prey; kingfishers were virtually absent from turbid water in the maritime provinces (Prose, 1985). Sediment incursions from bank erosions will likely affect the suitability of Site C as habitat for the belted kingfisher until conditions stabilize.

Because the belted kingfisher had the highest estimated dose among birds for all scenarios, risks for all other avian ROCs are therefore also considered negligible, with moderate uncertainty. Similarly, given that fish mercury concentrations downstream of Site C are expected to be less than half those seen within the reservoir (see **Section 2.2.3**), risks to wildlife feeding downstream of Site C are also considered negligible.

3.4.2 Mammals

When the estimated dose for the northern river otter (for the peak scenario) is plotted against the dose-response data for mammals (**Appendix F**), there is no indication of potential effects on survival, growth or reproduction. Thus, we conclude that risks to mammals are negligible. There is moderate uncertainty in this conclusion because there are limited data.

Because the northern river otter had the highest estimated dose among mammals and because the peak scenario had higher estimated doses than other scenarios, risks for all other mammals under other site C scenarios are therefore also considered negligible, with moderate uncertainty.

3.4.3 Amphibians

When the estimated dose for the western toad (0.00031 mg/kg wet day, **Table 3.2.4**) is compared to the dose-response data provided in **Table 3.3.1** for the Site C – Peak scenario, there is no indication of potential effects on survival, growth or reproduction; the calculated oral dose for the western toad is 0.2% of the lowest oral dose in the dose-response data. Thus, we conclude that risks to amphibians are negligible; however, there is high uncertainty in this conclusion because data are limited for both exposure factors (e.g., water and food ingestion rates for amphibians) and effects data (i.e., dose-response data).

3.5 Uncertainties

This section outlines key uncertainties and assumptions relevant to the LOE for wildlife. Where uncertainties were considered greater than “low”, potential implications for risk predictions were also discussed (e.g., potential for under- or over-estimating risks). Uncertainties are organized by the following groups:

- *Conceptual Site Model* – this refers to uncertainty in our understanding of the situation being assessed
- *Exposure* – this refers to WRA methods or assumptions that affect exposure estimates
- *Effects* – this refers to WRA methods or assumptions that affect compilation or interpretation of effects data
- *Risk Characterization* – this refers to the integration of exposure/effects information for individual organisms and its extrapolation to populations

Conceptual Site Model (CSM)

- *Contaminant sources* – Methylmercury-related changes in the aquatic environment associated with reservoir creation are reasonably well understood. The CSM was developed with these in mind to target this issue specifically, so uncertainty is low.
- *Environmental fate* – This assessment relied heavily on RESMERC, a sophisticated mechanistic model that has the ability to predict methylmercury concentrations in a wide range of environmental media at any point in time following reservoir creation. RESMERC explicitly considered mercury methylation, accumulation and biomagnification, important drivers of methylmercury transport and fate in the environment. More details regarding RESMERC are discussed below under "exposure". However, given that RESMERC is a model, uncertainty is considered moderate; based on an extensive review of many other Canadian reservoirs within the Mercury Technical Report (Volume 2, Appendix J, Part 1) RESMERC likely overestimates methylmercury concentrations in environmental media associated with Site C.
- *Exposure pathways* – It is well known that methylmercury biomagnifies up the aquatic food chain, with the highest concentrations found in predatory fish. Consequently, while including a range of ROC group (see below), the CSM incorporated piscivorous birds and mammals to ensure that this pathway was explicitly addressed. Uncertainty is considered low.
- *Receptors of concern (ROCs)* – ROCs included in this WRA represent a broad range of feeding types. ROCs are ultimately meant to conservatively represent the range of species found at a site. Wildlife biologists actively conducting field surveys related to Site C were consulted to select the most appropriate surrogate species for each feeding group. Consequently, uncertainty is considered low.

Exposure

- *Seasonality and foraging range factors* **–** These factors reflect temporal (seasonality) and spatial (foraging range) elements of contaminant exposure. Seasonality can be important if exposure occurs during non-breeding periods or for short durations (e.g., during migration stops only) as it may the relevancy of certain effect endpoints (e.g., reproduction or early development). In cases where an ROC's foraging range is much larger than the site, exposure may be diluted by the consumption of food items with lower contaminant concentrations. For Site C, exposure estimates were derived assuming no temporal or spatial constraints, which is considered realistic for this site and should not bias risk estimates. Consequently, uncertainty is considered low.

- *Predicted methylmercury concentrations* – This WRA relies on RESMERC for estimates of methylmercury concentrations in water, sediment, aquatic invertebrates, and fish within the Site C reservoir (**Appendix D**). Given that fish is the predominant source of methylmercury (e.g., 98% for the belted kingfisher for the Site C – Peak scenario), risk predictions are highly sensitive to estimated concentrations in fish. As discussed in **Section 11.9** of the EIS, the RESMERC model is considered to overestimate fish mercury concentrations for Site C by as much as 50% (e.g., RESMERC predicts peak concentrations to increase by up to 6 times relative to baseline, while two other lines of evidence indicate up to three fold changes). Consequently, uncertainty is considered moderate and the conservatism directly translates into over-estimation of methylmercury-related risks to ROCs.
- *Downstream of Site C* – While risk predictions focus on wildlife feeding from biota within the Site C reservoir there will be exposure to increased methylmercury in wildlife feeding on fish that may be entrained to the Peace River downstream of Site C. As laid out in the EIS (Section 11.9) the net increase of mercury in downstream fish is expected to be no more than half of what is expected within the reservoir, and for a smaller area and shorter duration than within Site C. Consequently, risks to downstream wildlife will necessarily be less than from within Site C reservoir.
- *Bioavailability* – Dietary uptake efficiency for methylmercury was assumed to be 100% of the ingested dose. This is considered a realistic assumption for methylmercury, so uncertainty is low.

- *Exposure pathways* – Food consumption, drinking water ingestion, and incidental ingestion of soil were assumed to represent 100% of the total COPC dose for a given wildlife receptor. This is likely realistic since exposure through inhalation and dermal contact are likely to be negligible, at least for birds and mammals; uncertainty is low.
- *Receptor-specific parameters* – Exposure parameters were compiled using available data and best professional judgment. Species-specific data on ingestion rates were often limited, requiring the use of allometric equations; this is common in food chain modeling and is not expected to bias results. Dietary composition can vary substantially over space and time; available literature data was coupled with professional judgment to select a reasonably conservative dietary composition. Overall, uncertainty is considered moderate and bias low.

Effects

- *Dose estimation* – In the absence of reported doses in the toxicological studies, assumptions were needed for one or more of the following: body weights, ingestion rates, or moisture content of food. Dose estimation can be variable, particularly for longer-term studies that include younger animals and adults. Overall, uncertainties associated with this are considered moderate; no bias is expected, so implications to risk predictions would be variable.
- *Interspecies extrapolation of dose-response data* – It was assumed that the dose-response data used in the effects assessment were appropriate for ROCs found in the study area. Application of the data assumes that the ROCs are similar in sensitivity to a given dose of methylmercury. Uncertainty would be moderate, but without bias.
- *Data quantity, quality and consistency* – Confidence in dose-response relationships increases with more, high-quality data that tell a consistent story. In the case of this WRA, confidence would differ for data sets generated for each ROC group. The degree to which confidence in the dose-response relationship results in meaningful uncertainty in a risk assessment depends on where predicted doses fall within the relationship. For birds, uncertainty is considered high because predicted doses (particularly for the belted

kingfisher) fall within the low end of the relationship for offspring reproduction, which happens to be quite variable. While data are more limited for mammals and highly limited for amphibians, uncertainty in each would be moderate as predicted doses fall below those associated with adverse effects.

Risk Characterization

- *Risk characterization* – Estimated exposure was compared to the available dose-response data using plots. Quantitative models were not fit to the dose-response data (because of data limitations); therefore interpretation of likely effect sizes associated with estimated dose was through visual interpretation of the data. There is some imprecision associated with this approach.
- *Extrapolation to local populations* – Results of the food chain model make predictions about potential effects to individual organisms. Individual organisms are relevant for listed species. However, for common species, the assessment endpoint usually focuses on local populations, which requires some extrapolation from organism-level measurement endpoints. Broadly speaking, if the magnitude of effects to organisms is considered negligible or low, potential risks to populations are unlikely to occur and uncertainty in this prediction may be considered low. However, if the magnitude of effects to organisms is moderate or high, potential implications for local populations are often unknown and require additional site-specific investigations to elucidate. Given that population modeling was used in this WRA to reduce uncertainties associated with the extrapolation of results, uncertainties would be considered low to moderate.

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TABLES

Table 2.3.1 Wildlife ROC selection and rationale for the Peace River Site C Clean Energy Project

Aquatic Receptor Group	Receptor Type	Included in ERA? (Yes/No)	Rationale	Surrogate ROC
Mammal	Herbivore	YES	Possible exposure to contaminants through ingestion of vegetation (aquatic and/or terrestrial), water and incidental ingestion of sediment and soil.	muskrat, moose, American beaver
	Insectivore	YES	Possible exposure to contaminants through ingestion of soil and/or aquatic invertebrates, water and incidental ingestion of sediment and soil.	little brown myotis,
	Piscivore/Carnivore	YES	Possible exposure to contaminants through ingestion of fish and/or small mammals, water and incidental ingestion of sediment and soil.	northern river otter, American mink
	Omnivore	YES	Possible exposure to contaminants through ingestion of food, water and incidental ingestion of sediment and soil.	muskrat - (represents an omnivore for this food chain model, but none of the mammals chosen are true omnivores)
Bird	Herbivore	YES	Possible exposure to contaminants through ingestion of vegetation (aquatic and/or terrestrial), water and incidental ingestion of sediment and soil.	Canada goose
	Insectivore	YES	Possible exposure to contaminants through ingestion of soil and/or aquatic invertebrates, water and incidental ingestion of sediment and soil.	spotted sandpiper, bank swallow
	Piscivore/Carnivore	YES	Possible exposure to contaminants through ingestion of fish and/or small mammals, water and incidental ingestion of sediment and soil.	belted kingfisher, common merganser, bald eagle
	Omnivore	YES	Possible exposure to contaminants through ingestion of food, water and incidental ingestion of sediment and soil.	mallard
Amphibian	Carnivore	YES	Exposure through direct contact with surface soil/sediment and water, ingestion of food (prey such as invertebrates), uptake of drinking water and inadvertent ingestion of soil and sediment.	western toad

Table 2.4.1. Aquatic exposure pathway selection and rationale for the Site C Clean Energy Project

Receptor Group	Aquatic Exposure Pathway	Included (yes/no)	Rationale
Mammals	Water consumption	YES	Mammals are expected to drink from Site water.
	Food consumption	YES	Mammals expected to use aquatic food sources on Site (e.g., plants, invertebrates,fish).
	Incidental sediment ingestion	YES	Incidental sediment ingestion is expected, particularly for mammals that forage near the sediment/water interface (e.g.muskrat).
Birds	Water consumption	YES	Birds are expected to drink from Site water.
	Food consumption	YES	Birds expected to use aquatic food sources (plants, invertebrates, fish, flying insects [which have an aquatic origin]) on site.
	Incidental soil ingestion	YES	Incidental sediment ingestion expected, particularly for birds that forage near the sediment/water interface (e.g., mallard).
Amphibians	Water consumption	YES	Amphibians may be exposed through water ingestion.
	Food consumption	YES	Amphibians may be exposed to contaminants via diet.
	Incidental sediment ingestion	YES	Amphibians may be exposed to contaminants in soil and sediment through incidental ingestion .
	Incidental soil ingestion	YES	
	Direct contact with water, soils and sediments	YES	Amphibians are in contact with water, soils and sediments; amphibian skin is permeable.

Table 2.6.1. Endpoints and lines of evidence for the Site C Clean Energy Project.

Receptor Groups	Assessment Endpoint	LOE #	LOE Category (Tool)	LOE Description and Measurement Endpoints
Birds, Mammals and Amphibians	Viability[(a)] of local bird and mammal populations[(b)] (for common species); survival, reproduction, growth, and deformities of individual organisms[(c)] (for listed species); entity assumed to be represented by the entire property (for both common and listed species)	1	Food chain model	Comparison of estimated total dose (from a food chain model using measured contaminant concentrations in dietary items) to a literature-derived dose-response dataset, to qualitatively determine the magnitude of potential risks.

NOTES:

(a) We define viability as the ability of a population to sustain itself over the long term. We assume that assessing organism level attributes will be protective of population attributes.

(b) The assessment population consists of a group of conspecific organisms occupying a defined area that has been selected to serve as an assessment endpoint entity for the ecological risk assessment (Barnthouse et al. 2008). The assessment population is operationally defined in the risk assessment as the local population, which consists of all organisms exposed to, or indirectly affected by, contaminants at the Site.

(c) The measurement endpoint is based on an average individual within a test population.

Table 3.2.1. Methyl mercury exposure concentrations for each of four exposure scenarios

<table>
<tr><th>Exposure Media</th><th>Parameters</th><th>Peace - Baseline</th><th>Site C - Peak</th><th>Site C - Peak Average</th><th>Site C - Long Term</th></tr>
<tr><td colspan="6">Terrestrial Exposure Media</td></tr>
<tr><td rowspan="3">Soil</td><td>Value (mg/kg)</td><td>0.000245</td><td colspan="3">0.000245</td></tr>
<tr><td>Source</td><td>Azimuth 2011</td><td colspan="3">Azimuth 2011</td></tr>
<tr><td>Description</td><td>Environmental Data - 95% UCLM of the baseline soil methyl mercury concentrations within reservoir footprint collected in 2010. Used only subset of data with methyl mercury (12 samples) , currently without Watson Slough and Fire-impacted sample. The subset of data reflects the range of concentrations present in the entire soil dataset, with perhaps the exception of the lower range of mercury concentrations (see Figure 3.2.1).</td><td colspan="3">Surrogate Data -Soils from Baseline Peace River used as a surrogate, assumed that soils upland of the Site C Reservoir that will remain unflooded are similar.</td></tr>
<tr><td rowspan="3">Shrubs/Trees</td><td>Value (mg/kg ww)</td><td>0.00117</td><td colspan="3">0.00117</td></tr>
<tr><td>Source</td><td>Azimuth 2011, Moore et al. 1995</td><td colspan="3">Azimuth 2011</td></tr>
<tr><td>Description</td><td>Environmental Data - 30% of the 95% UCLM for total mercury from 2010 shrub/tree data along Peace River (including sarsaparilla, rose, dogwood, willow, spruce and alder samples, total of 14 samples). 30% is estimated by Azimuth from data presented in Moore et al. 1995.</td><td colspan="3">Surrogate Data -Shrubs/trees from Baseline Peace River Scenario; assumed to be the same for future Site C Scenarios.</td></tr>
<tr><td rowspan="3">Grasses/Herbs</td><td>Value (mg/kg ww)</td><td>0.00192</td><td colspan="3">0.00192</td></tr>
<tr><td>Source</td><td>Azimuth 2011, Moore et al. 1995</td><td colspan="3">Azimuth 2011</td></tr>
<tr><td>Description</td><td>Environmental Data -30% of the maximum total mercury concentrations of 2010 data for grasses/herbs along Peace River (including horsetails, sedges, reeds and cattails, total of 5 samples). The maximum was used instead of a 95% UCLM as the calculated 95% UCLM was greater than observed maximum. 30% is estimated by Azimuth from data presented in Moore et al. 1995.</td><td colspan="3">Surrogate Data -Grasses/herbs from Baseline Peace River Scenario; assumed to be the same for future Site C Scenarios.</td></tr>
<tr><td rowspan="3">Small animals</td><td>Value (mg/kg ww)</td><td>0.0002548</td><td colspan="3">0.0002548</td></tr>
<tr><td>Source</td><td>Azimuth 2011, Gnamus and Horvat, 1999,USEPA 1993</td><td colspan="3">Azimuth 2011, Gnamus and Horvat, 1999,US EPA 1993</td></tr>
<tr><td>Description</td><td>Predicted Data- Calculated using a Biaccumulation Factor (Uptake Factor of 3.25 from Gnamus and Horvat 1999) and the Baseline Peace River soil methyl mercury concentration (see soil, above). Dry weight concentrations were converted to wet weight using a moisture content of 68% (USEPA 1993).</td><td colspan="3">Predicted Data - Calculated as per Baseline Peace River. Baseline Peace River soil concentrations (surrogate soils, assumed that soils upland of the Site C Reservoir that will remain unflooded are similar).</td></tr>
<tr><td rowspan="3">Earthworms</td><td>Value (mg/kg ww)</td><td>0.0003136</td><td colspan="3">0.0003136</td></tr>
<tr><td>Source</td><td>Azimuth 2011, Allard et al. 2003, USEPA 1993</td><td colspan="3">Azimuth 2011, Allard et al. 2003, US EPA 1993</td></tr>
<tr><td>Description</td><td>Predicted Data - Calculated using a Biaccumulation Factor (Uptake Factor of 8 from Allard et al. 2003) and the Baseline Peace River soil methyl mercury concentration (see soil, above). Dry weight concentrations were converted to wet weight using a moisture content of 84% (USEPA 1993).</td><td colspan="3">Predicted Data - Calculated as per Baseline Peace River. Baseline Peace River soil concentrations (surrogate soils, assumed that soils upland of the Site C Reservoir that will remain unflooded are similar).</td></tr>
</table>

Table 3.2.1. Methyl mercury exposure concentrations for each of four exposure scenarios

Exposure Media	Parameters	Peace - Baseline	Site C - Peak	Site C - Peak Average	Site C - Long Term
Ground Insects	Value (mg/kg ww)	0.000686	0.000686		
	Source	Azimuth 2011, Allard et al. 2003, USEPA 1993	Azimuth 2011, Allard et al. 2003, US EPA 1993		
	Description	**Predicted Data** - Calculated using a Biaccumulation Factor (Uptake Factor of 8 from Allard et al. 2003) and the Baseline Peace River soil methyl mercury concentration (see soil, above). Dry weight concentrations were converted to wet weight using a moisture content of 65% (USEPA 1993).	**Predicted Data** - Calculated as per Baseline Peace River. Baseline Peace River soil concentrations (surrogate soils, assumed that soils upland of the Site C Reservoir that will remain unflooded are similar).		
Flying Insects	Value (mg/kg ww)	0.0015	0.0070	0.0059	0.0017
	Source	Azimuth 2011, Allard et al. 2003, US EPA 1993			
	Description	**Surrogate Data** - Concentrations for all four scenarios assumed to be 50% ground insects (see above) and 50% aquatic invertebrates (see below).			
Aquatic Exposure Media					
Water	Value (mg/L)	2.06E-08	3.59E-08	3.19E-08	2.10E-08
	Source	Harris and Hutchinson 2013			
	Description	**RESMERC**– Water concentrations for all four scenarios were based on modelled predictions of water concentrations (Harris and Hutchinson 2013) for upstream and downstream reaches. Only concentrations predicted for the epilimnion were used, water from the hypolimnion was not considered accessible as drinking water to wildlife. Methylmercury concentrations were area weighted for upstream and downstream reaches to provide one estimate for each scenario.			
Sediment	Value (mg/kg)	0.0011	0.0137	0.0098	0.0012
	Source	Harris and Hutchinson 2013			
	Description	**RESMERC**– Sediment concentrations for all four scenarios were based on modelled predictions of sediment concentrations (Harris and Hutchinson 2013) for upstream and downstream reaches including original riverbed sediments, flooded uplands and flooded wetlands. Only concentrations predicted for the epilimnion were used, sediment from the hypolimnion was not considered accessible to wildlife. Methylmercury concentrations were area weighted for upstream and downstream reaches to provide one estimate for each scenario.			
Aquatic plants	Value (mg/kg ww)	0.0019	0.0019	0.0019	0.0018
	Source	Haris and Hutchinson 2013, Moore 1995, unpublished field study data (Azimuth)			
	Description	**BCF calculation** - Based on: (1) bioconcentration factors (BCF) for total mercury; (2) Baseline Peace River maximum total unfiltered mercury water concentrations obtained from RESMERC (concentrations were area-weighted for upstream and downstream reaches and only water from the epilimnion was used); and (3) the assumption that methyl mercury is approximately 36% of total mercury in aquatic plants (Moore et al. 1995). A BCF of 7000 was selected based on unpublished field studies using Canadian macrophytes (unusually high and low BCFs were discounted).			
Aquatic inverts (for receptors which feed from the water-column and/or sediments)	Value (mg/kg ww)	0.0023	0.0161	0.0133	0.0023
	Source	Harris and Hutchinson 2013			
	Description	**RESMERC** – Invertebrate concentrations for all four scenarios were based on modelled predictions of invertebrate concentrations (RESMERC, Harris and Hutchinson 2013) for both benthos (sediment-associated invertebrates) and water-column invertebrates. For benthos, concentrations used in the model were estimated based on upstream and downstream reaches, including original riverbed sediments, flooded upland and flooded wetlands. Only concentrations predicted for the epilimnion were used, invertebrates from the hypolimnion were not considered accessible to wildlife. Benthos and water-column invertebrate concentrations were each separately area weighted for upstream and downstream reaches and then combined using a 50/50 ratio to provide one estimate for each scenario. Where necessary, concentrations were converted from dry to weight wet using an 89% moisture concentration (to be consistent with RESMERC).			

Table 3.2.1. Methyl mercury exposure concentrations for each of four exposure scenarios

Exposure Media	Parameters	Peace - Baseline	Site C - Peak	Site C - Peak Average	Site C - Long Term
Aquatic inverts (for calculation of flying insect concentrations)	Value (mg/kg ww)	0.0023	0.0134	0.0112	0.0027
	Source	Harris and Hutchinson 2013			
	Description	**RESMERC** - Invertebrate concentrations for the estimation of flying insect concentrations were calculated as above; however, both epilimnion and hypolimnion benthos concentrations were used. A portion of the benthos from the hypolimnion is expected to emerge and take on a terrestrial flying insect phase.			
Amphibians	Value (mg/kg ww)	0.018	0.084	0.072	0.020
	Source	Harris and Hutchinson 2013			
	Description	**Surrogate Data** - Tissue concentrations of amphibians were estimated to be similar to the smallest size rainbow trout modelled by RESMERC (0+) due to: (1) lack of amphibian data, and (2) some potential similarities in diet (both eat some portion of terrestrial insects).			
Fish (< 120 mm)	Value (mg/kg ww)	0.021	0.093	0.082	0.026
	Source	Harris and Hutchinson 2013			
	Description	**RESMERC -** Fish methylmercury concentrations for all four scenarios was taken from the RESMERC model (Harris and Hutchinson) for four fish species expected to reside in the reservoir, including rainbow trout, bull trout, red side shiner and longnose sucker. Fish (any of the four species) in age classes with total lengths equal to or less than 120 mm were weighted by the predicted biomass for this size fish to obtain a methylmercury concentration for each scenario.			
Fish (<300 mm)	Value (mg/kg ww)	0.027	0.116	0.105	0.033
	Source	Harris and Hutchinson 2013			
	Description	**RESMERC -** Fish methylmercury concentrations for all four scenarios was taken from the RESMERC model (Harris and Hutchinson) for four fish species expected to reside in the reservoir, including rainbow trout, bull trout, red side shiner and longnose sucker. Fish (any of the four species) in age classes with total lengths equal to or less than 120 mm were weighted by the predicted biomass for this size fish to obtain a methylmercury concentration for each scenario.			
Fish (<500 mm)	Value (mg/kg ww)	0.027	0.117	0.106	0.033
	Source	Harris and Hutchinson 2013			
	Description	**RESMERC -** Fish methylmercury concentrations for all four scenarios was taken from the RESMERC model (Harris and Hutchinson) for four fish species expected to reside in the reservoir, including rainbow trout, bull trout, red side shiner and longnose sucker. Fish (any of the four species) in age classes with total lengths equal to or less than 120 mm were weighted by the predicted biomass for this size fish to obtain a methylmercury concentration for each scenario.			

NOTES:
RESMERC - Reservoir mercury model
ww - wet weight
UCLM - Upper confidence limit of the mean
BCF - Bioconcentration factor
BAF - Bioaccumulation factor
USEPA - United States Environmental Protection Agency

Table 3.2.2. Receptor Specific Parameters for Receptors of Concern

Species and Parameters	Units	Value	Reference	Notes [a]
American beaver				
BW	kg wet	19.000	Fryxell and Doucet (1993); Wheatley (1997); Hatler (2002); Nagorsen (2005)	
I_{water}	L/kg wet/day	0.074	USEPA (1993)	Based on allometric equation for all mammals ($I_{water} = 0.099*BW^{0.90}$)
I_{soil}	kg dry/kg wet/day	0.001	na	Assumed 2% of dry food ingestion rate
$I_{sediment}$	kg dry/kg wet/day	0.001	na	Assumed 2% of dry food ingestion rate
I_{food}	kg wet/kg wet/day	0.149		Based on total dry food intake (see below), and a moisture content in food of 73%
FI	kg dry/kg wet/day	0.041	USEPA (1993)	Based on allometric equation for total dry food ingestion rate for all mammals ($0.235*BW^{0.822}$)
moose				
BW	kg wet	400.0	FCSAP 2012b	Based on average body weight of both sexes (Banfield 1974)
I_{water}	L/kg wet/day	0.050	FCSAP 2012b	Based on allometric equation for all mammals (L/day) ($Iwater = 0.099*BW^{0.90}$)
I_{soil}	kg dry/kg wet/day	0.0004	FCSAP 2012b	Assumed 2% of dry food ingestion rate
$I_{sediment}$	kg dry/kg wet/day	0.0004	na	Assumed 2% of dry food ingestion rate
I_{food}	kg wet/kg wet/day	0.068	na	Based on total dry food intake (see below), and a moisture content in food of 71%
FI	kg dry/kg wet/day	0.020	FCSAP 2012b	Based on a dry matter intake for two free-ranging female moose (Renecker and Hudson 1985)
muskrat				
BW	kg wet	1.000	FCSAP 2012b	(Banfield 1974; Nagorsen 2005)
I_{water}	L/kg wet/day	0.100	FCSAP 2012b	Based on allometric equation for all mammals (L/day) ($Iwater = 0.099*BW^{0.90}$)
I_{soil}	kg dry/kg wet/day	0.000	na	Assumed negligible
$I_{sediment}$	kg dry/kg wet/day	0.001	na	Assumed 2% of dry food ingestion rate
I_{food}	kg wet/kg wet/day	0.481	na	Based on dry food intake (see below) and moisture content in food of 85%
FI	kg dry/kg wet/day	0.070	FCSAP 2012b	Based on captured muskrats (both males and females, all age classes) fed a natural diet (Campbell and MacArthur 1996).
northern river otter				
BW	kg wet	7.500	FCSAP 2012b	Based on average body weight of both sexes (Lariviere and Walton 1998)
I_{water}	L/kg wet/day	0.080	FCSAP 2012b	Based on allometric equation for all mammals (L/day) ($Iwater = 0.099*BW^{0.90)}$
I_{soil}	kg dry/kg wet/day	0.000	na	Assumed negligible
$I_{sediment}$	kg dry/kg wet/day	0.001	na	Assumed 2% of dry food ingestion rate
I_{food}	kg wet/kg wet/day	0.135	na	Based on dry food intake (see below) and moisture content in food of 78%
FI	kg dry/kg wet/day	0.030	FCSAP 2012b	Based on farmed male river otters (Davis et al. 1992)
American mink				
BW	kg wet	0.820	FCSAP 2012b	Based on average body weigt of both sexes (McCabe 1949)
I_{water}	L/kg wet/day	0.030	FCSAP 2012b	This rate is based on an adult farm raised female (in USEPA 1993) in g/g day (assumes water density of 1 g/ml).
I_{soil}	kg dry/kg wet/day	0.0007	na	Assumed 2% of dry food ingestion rate
$I_{sediment}$	kg dry/kg wet/day	0.0007	na	Assumed 2% of dry food ingestion rate
I_{food}	kg wet/kg wet/day	0.140	FCSAP 2012b	Based on ingestion rates for farm raised adults, both sexes as reported in the USEPA (1993)
FI	kg dry/kg wet/day	0.034	na	Based on wet food intake (see above) and moisture content in food of 76%
little brown bat				
BW	kg wet	0.007	Barclay (1991); Nagorsen and Brigham (1993)	
I_{water}	L/kg wet/day	0.160	USEPA (1993)	Based on allometric equation for all mammals ($I_{water} = 0.099*BW^{0.90}$)
I_{soil}	kg dry/kg wet/day	0.000	na	Assumed negligible
$I_{sediment}$	kg dry/kg wet/day	0.000	na	Assumed negligible
I_{food}	kg wet/kg wet/day	1.120	Sample et al. (1997)	Based on 1.12 g/g/day ingestion rate for adults in the field
FI	kg dry/kg wet/day	0.392	USEPA (1993)	Based on wet food intake (see above) and moisture content in food of 65%
Canada goose				
BW	kg wet	2.000	Sedinger and Raveling 1984; Prevett et al. 1985; Campbell et al. 1990; Reed et al. 1996; Mowbray et al. 2002	Based on average weight of both sexes
I_{water}	L/kg wet/day	0.047	USEPA (1993)	Based on allometric equation for all birds (L/day) ($0.059(BW)^{0.67}$)
I_{soil}	kg dry/kg wet/day	0.001	na	Assumed 2% of dry food ingestion rate
$I_{sediment}$	kg dry/kg wet/day	0.000	na	Assumed negligible
I_{food}	kg wet/kg wet/day	0.129	na	Based on dry food intake (see below) for all birds and moisture content of food of 65%
FI	kg dry/kg wet/day	0.046	USEPA (1993)	Based on allometric equation for total dry food ingestion rate for all birds (g/day) ($0.648*(BW)^{0.651}$)
mallard				
BW	kg wet	1.200	FCSAP 2012b	Based on average body weight of both sexes (Bellrose 1976)
I_{water}	L/kg wet/day	0.060	FCSAP 2012b	Based on allometric equation for all birds (L/day) ($0.059(BW)^{0.67}$)
I_{soil}	kg dry/kg wet/day	0.000	na	Assumed negligible
$I_{sediment}$	kg dry/kg wet/day	0.001	FCSAP 2012b	Assumed 2% of dry food ingestion rate
I_{food}	kg wet/kg wet/day	0.278	na	Based on dry food intake (see below) and moisture content in food of 82%
FI	kg dry/kg wet/day	0.050	FCSAP 2012b	Based on allometric equation for total dry food ingestion rate for all birds (g/day) ($0.648*(BW)^{0.651}$)
bank swallow				
BW	kg wet	0.014	Peterson 1955	Based on average adult body weight of both sexes
I_{water}	L/kg wet/day	0.241	USEPA (1993)	Based on allometric equation for all birds ($I_{water} = 0.059*BW^{0.67}$)
I_{soil}	kg dry/kg wet/day	0.027	na	Assumed 10% of dry food ingestion rate (to reflect increased exposure to soil/mud during nest building)
$I_{sediment}$	kg dry/kg wet/day	0.000	na	Assumed negligible
I_{food}	kg wet/kg wet/day	0.765	na	Based on dry food intake (see below) and moisture content of food of 65%
FI	kg dry/kg wet/day	0.268	USEPA (1993)	Based on allometric equation for total dry food ingestion rate for passerine birds (g/day) ($0.398(BW)^{0.850}$)

Table 3.2.2. Receptor Specific Parameters for Receptors of Concern

Species and Parameters	Units	Value	Reference	Notes [a]
spotted sandpiper				
BW	kg wet	0.038	FCSAP 2012b	Based on the average body weight of both sexes (Irving 1960)
I_{water}	L/kg wet/day	0.170	FCSAP 2012b	Based on allometric equation for all birds (L/day) $(0.059(BW)^{0.67})$
I_{soil}	kg dry/kg wet/day	0.004	na	Assumed 2% of dry food ingestion rate
$I_{sediment}$	kg dry/kg wet/day	0.004	na	Assumed negligible
I_{food}	kg wet/kg wet/day	0.757	na	Based on dry food intake (see below) and moisture content in food of 76%
FI	kg dry/kg wet/day	0.180	FCSAP 2012b	Based on allometric equation for total dry food ingestion rate for all birds (g/day) $(0.648*(BW)^{0.651})$
bald eagle				
BW	kg wet	4.700	FCSAP 2012b	Based on average body weight of both sexes (Imler and Kalmbach 1955)
I_{water}	L/kg wet/day	0.040	FCSAP 2012b	Based on allometric equation for all birds (L/day) $(0.059(BW)^{0.67})$
I_{soil}	kg dry/kg wet/day	0.000	na	assumed negligible
$I_{sediment}$	kg dry/kg wet/day	0.000	na	assumed negligible
I_{food}	kg wet/kg wet/day	0.120	FCSAP 2012b	Based on 0.12 g/g day ingestion rate for adults, both sexes
FI	kg dry/kg wet/day	0.031	na	Based on wet food intake (see above) and moisture content in food of 75%
common merganser				
BW	kg wet	1.500	FCSAP 2012b	Based on the average body weight of both sexes (Erskine 1972; Cramp and Simmons 1977)
I_{water}	L/kg wet/day	0.050	FCSAP 2012b	Based on allometric equation for all birds (L/day) $(0.059(BW)^{0.67})$
I_{soil}	kg dry/kg wet/day	0.000	na	Assumed negligible
$I_{sediment}$	kg dry/kg wet/day	0.001	na	Assumed 2% of dry food ingestion rate
I_{food}	kg wet/kg wet/day	0.231	na	Based on dry food intake and moisture content in food of 78%
FI	kg dry/kg wet/day	0.050	FCSAP 2012b	Based on allometric equation for total dry food ingestion rate for all birds (g/day) $(0.648*(BW)^{0.651})$
belted kingfisher				
BW	kg wet	0.147	USEPA (1993)	Based on adults, both sexes
I_{water}	L/kg wet/day	0.111	USEPA (1993)	Based on allometric equation for all birds $(I_{water} = 0.059*BW^{0.67})$
I_{soil}	kg dry/kg wet/day	0.000	na	Assumed negligible
$I_{sediment}$	kg dry/kg wet/day	0.000	na	Assumed negligible
I_{food}	kg wet/kg wet/day	0.509	USEPA (1993)	Based on allometric equation for all birds and moisture content in food of 78%)
FI	kg dry/kg wet/day	0.113	USEPA (1993)	Based on allometric equation for total dry food ingestion rate for all birds (g/day) $(0.648(BW)^{0.651})$
western toad				
BW	kg wet	0.005	Lillywhite et al. (1973)	Based on juvenile life stage, since feeding rate is based on juvenile
I_{water}	L/kg wet/day	0.076	n/a	Assumed equivalent to food intake
I_{soil}	kg dry/kg wet/day	0.002	n/a	Asssumed 10% of dry food intake
$I_{sediment}$	kg dry/kg wet/day	0.001	n/a	Asssumed 5% of dry food intake
I_{food}	kg wet/kg wet/day	0.076	Lillywhite et al. (1973)	Lillywhite (1973) + Unrine & Jagoe (2004) data for juvenile
FI	kg dry/kg wet/day	0.020	Unrine & Jagoe (2004)	Diet was 74% moisture

NOTES:

(a) Moisture content of foods was estimated using dietary preferences specified in Table 3.2.3, and moisture content of foods in USEPA 1993 or site-specific moisture where available.

USEPA - United States Environmental Protection Agency
EC - Environment Canada
BW - body weight
I_{water} -water ingestion rate
I_{soil} -soil ingestion rate
$I_{sediment}$ -sediment ingestion rate
I_{food} - food ingestion rate (wet)
FI - food ingestion rate (dry)

Table 3.2.3. Dietary preferences and foraging range of Receptors of Concern

ROC Feeding Guild	Species	Status	Dietary Preferences (%)									References
			Grasses / Herbs	Shrubs / Trees	Ground Insects / Earthworms	Flying Insects	Small Mammals / Birds	Aquatic Plants	Aquatic Invertebrates	Amphibians	Fish	
Medium herbivorous mammals	American beaver (*Castor canadensis*)			70				30				Hall 1960; Banfield 1974; Fryxell and Doucet 1993; Wheatley 1997; Eder and Pattie 2001; Nagorsen 2005
Large herbivorous mammals	moose (*Alces alces)*			80				20				FCSAP 2012b
Medium omnivorous mammals	muskrat (*Ondatra zibethicus*)				1		1	80	15	1	2	FCSAP 2012b
Medium carnivorous mammals	northern river otter (*Lontra canadensis*)						5		15		80	FCSAP 2012b
	American mink (*Mustela Vison*) [(d)]				10		30		10	15	35	FCSAP 2012b
Insectivorous bat	little brown myotis (*Myotis lucifugus)*					100						Barclay 1991; Nagorsen and Brigham 1993
Herbivorous birds	Canada goose (*Branta canadensis*)		75 [(a)]	5				20				Sedinger and Raveling 1984; Prevett et al. 1985; Campbell et al. 1990; Reed et al. 1996; Mowbray et al. 2002
Omnivorous birds	mallard (*Anas platyrhynchos*)		5 [(b)]		2	2		50	40		1	FCSAP 2012b
Insectivorous birds	bank swallow (*Riparia riparia*)					100						Garrison 1998
	spotted sandpiper (*Actitis macularia*)				50	10		5	30	3	2	FCSAP 2012b
Predatory birds	bald eagle (*Haliaeetus leucocephalus)*						35				65	FCSAP 2012b
Piscivorous birds	common merganser (*Mergus merganser*)							2	8		90	FCSAP 2012b
	belted kingfisher *(Megaceryle alcyon*)		1 [(c)]		1	2	1		10		85	White 1953; Davis 1982; Brooks and Davis 1987; Ehrlich et al. 1988; Kelly 1996; Albano 2000; Kelly at al. 2009
Amphibians	western toad (*Bufo boreas)*	Species of Concern			70	15			15			Jones and Goettl 1998; Davis 2000; Wind and Dupuis 2002; Matsuda et al. 2006

NOTES:

EC - Environment Canada

ROC - Receptor of Concern

(a) 15% berries and seed included as herbs/grasses as berries and seeds were not sampled.

(b) 5% berries and seeds included as herbs/grasses as berries and seeds were not sampled

(c) 1% berries and seeds included as herbs/grasses as berries and seeds were not sampled

(d) 25% crustacean dietary component evenly split between food items - crustaceans not expected to be present in reservor.

Table 3.2.4. Summary of total methylmercury doses for Receptors of Concern (mg/kg wet weight per day)

ROC	Peace - Baseline	Site C - Peak	Site C - Peak Average	Site C - Long Term
American beaver	2.070E-4	2.192E-4	2.134E-4	2.040E-4
moose	8.993E-5	9.555E-5	9.320E-5	8.902E-5
muskrat	1.181E-3	3.222E-3	2.833E-3	1.208E-3
northern river otter	2.948E-3	1.292E-2	1.160E-2	3.622E-3
American mink	1.751E-3	7.724E-3	6.863E-3	2.084E-3
little brown myotis	1.698E-3	7.890E-3	6.643E-3	1.918E-3
Canada goose	2.423E-4	2.435E-4	2.420E-4	2.406E-4
mallard	6.171E-4	2.401E-3	2.040E-3	6.199E-4
bank swallow	1.167E-3	5.399E-3	4.546E-3	1.317E-3
spotted sandpiper	1.639E-3	7.777E-3	6.627E-3	1.752E-3
bald eagle	2.119E-3	9.173E-3	8.250E-3	2.610E-3
common merganser	4.352E-3	1.965E-2	1.738E-2	5.407E-3
belted kingfisher	9.061E-3	4.098E-2	3.625E-2	1.125E-2
western toad	7.231E-5	3.053E-4	2.566E-4	7.428E-5

Table 3.3.1. Summary of amphibian dose-response data from Unrine et al. (2004)

	Oral Dose MeHg (mg/kg wet/day) [(a)]	Survival Rate (%) [(b)]	Metamorphic Success Rate [(c)]	Malformation Rate [(d)]	Average Tail Resorpion Time [(b)] (days)	Summary of Effects Relative to Control
Control	0.121	88.2%	82.4%	5.9%	11.7	
Low Dose	0.146	100.0%	100.0%	5.6%	13.0	No change in survival, metamorphic success rate, or malformation rate, but tail resorption time was approximately 10% slower.
Medium Dose	0.272	***72.2%***	***66.7%***	11.1%	15.5 *	Survival was 16% lower, metamorphic success rate was 16% lower, malformation rate was 47% higher, and tail resorption time was 25% slower.
High Dose	0.504	***72.2%***	***72.2%***	27.8%	***14 ****	Survival was 16% lower, metamorphic success rate was 10% lower, malformation rate was 79% higher, and tail resorption time was 16% slower.

NOTES:

MeHg - methylmercury

(a) Oral dose calculated using dietary dose concentrations from Unrine et al. (2004), average feeding rate of 180 mg/day (Unrine and Jagoe 2004) and average body weight of 4.6 g (Lillywhite 1973).

(b) Log-likelihood ratio tests used to assess the relationship between survival of larve and mercury treatment; survival was found to be dependent on mercury treatment (G= 9.6576, p=0.0406, df=3).

(c) Log-likelihood ratio tests were to assess the relationship between metamorphic success rate and mercury treatment; rate was found to be dependent on mercury treatment (G=10.4703, p=0.0293, df=3).

(d) Log-logistic concentration response model used to assess the relationship between malformation rate and mercury treatment; rate was found to well explained by mercury treatment (r^2= 0.9945, p= 0.0475).

(e) Time between forelimb emergence and complete tail resorption. Estimated from Figure 5 of Unrine et al. (2004).* Significantly different at $p < 0.05$

> 10% negative effect relative to control

> 20% negative effect relative to control

Table 3.4.1 Dose and reproductive output for bird ROCs under the four Site C exposure scenarios.

	Dose (mg/kg/day)				Relative Performance (% of Lab Control)				Relative Response (% Less than Peace - Baseline)		
Receptor of Concern	Peace - Baseline	Site C - Peak	Site C - Peak Av.	Site C - Long Term	Peace - Baseline	Site C - Peak	Site C - Peak Av.	Site C - Long Term	Site C - Peak	Site C - Peak Av.	Site C - Long Term
Canada Goose	0.0002	0.0002	0.0002	0.0002	99	99	99	99	0	0	0
Mallard	0.0006	0.0024	0.0020	0.0006	98	96	96	98	3	2	0
Bank Swallow	0.0012	0.0054	0.0046	0.0013	97	93	93	97	5	4	0
Spotted Sandpiper	0.0016	0.0078	0.0066	0.0018	97	91	92	97	6	5	0
Bald Eagle	0.0021	0.0092	0.0083	0.0026	96	90	90	96	7	6	1
Common Merganser	0.0044	0.020	0.017	0.0054	94	83	85	93	11	10	1
Belted Kingfisher	0.0091	0.041	0.036	0.013	90	75	76	87	17	15	3

FIGURES

Figure 2.1.1. 'Typical' time course projection of methylmercury concentration (mg/kg) in a carnivorous fish following impoundment of a large reservoir.

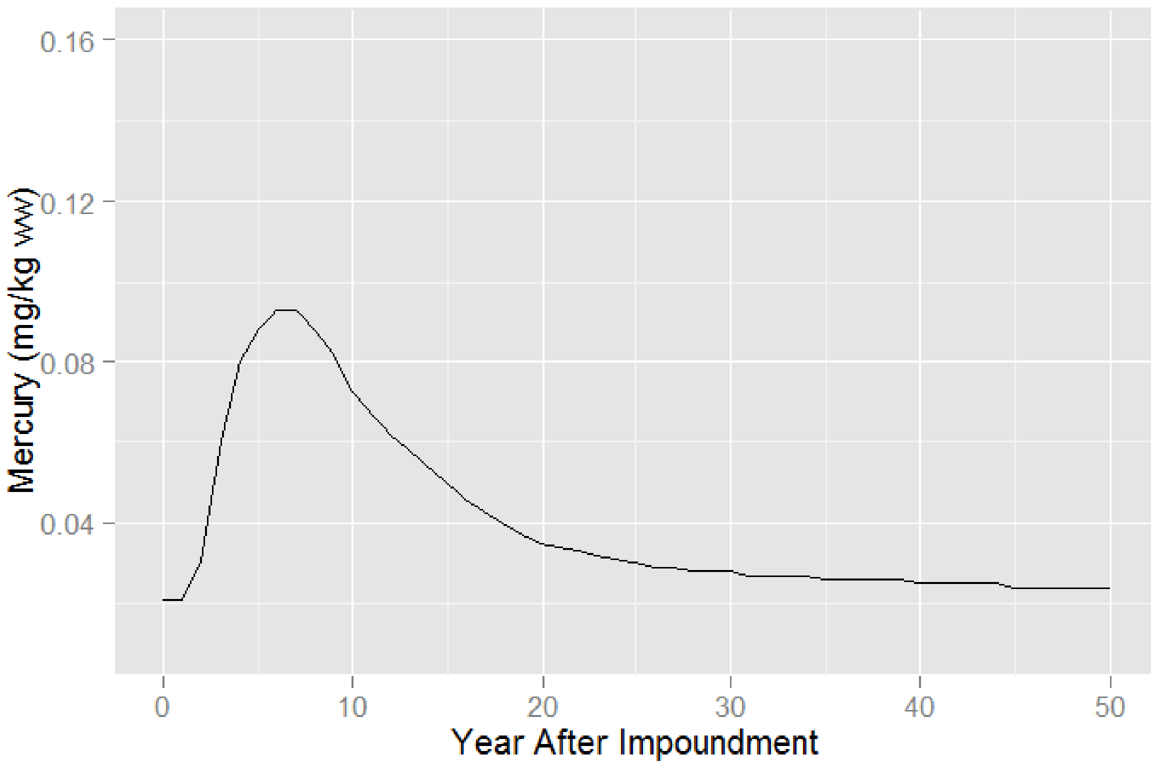


Figure 2.1.2. Depiction of the four temporal scenario's addressed to determine effects to ROCs from dietary methylmercury exposure

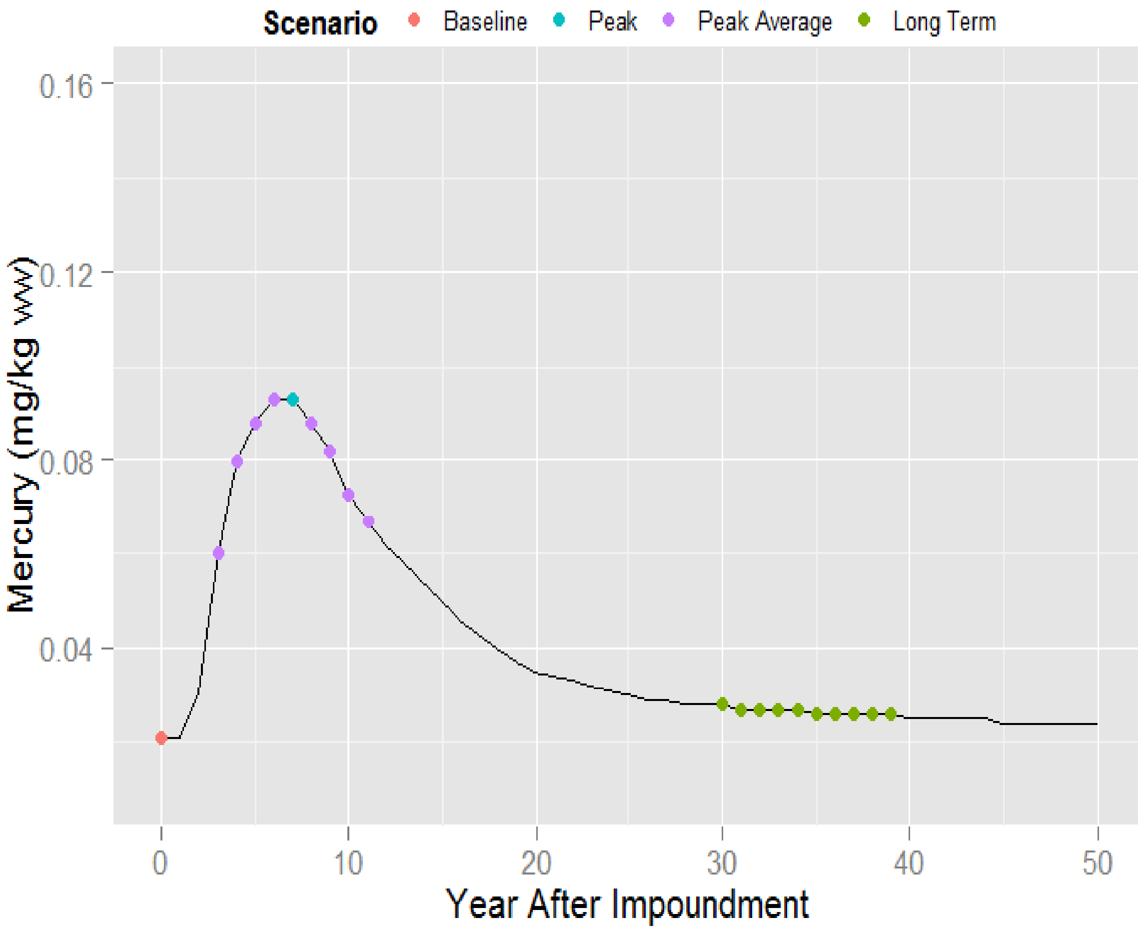


Figure 2.4.1. Conceptual exposure model

Primary Sources	Fate and Transport	Exposure Media	Exposure Pathways	Receptors of Potential Concern													
				Mammals						Birds							
				muskrat	moose	American beaver	northern river otter	American mink	little brown myotis	Canada goose	spotted sandiper	bank swallow	belted kingfishr	common merganser	bald eagle	mallard	western toad
Reservoir Sources	→	Sediments and porewater	Incidental ingestion	•	•	•	•	•	○	•	•	○	○	•	○	•	
		Surface water	Ingestion/Absorption through skin	•	•	•	•	•	•	•	•	•	•	•	•	•	•
		Plant Tissues	Ingestion	•	•	•	○	○	○	•	•	○	○	•	○	•	○
		Invertebrate Tissues	Ingestion	•	○	○	•	•	○	○	•	○	•	•	○	•	•
		Flying Insects	Ingestion	○	○	○	○	○	•	○	•	•	•	○	○	•	•
		Fish Tissue (small)	Ingestion	•	○	○	•	•	○	○	• *	○	•	•	•	• *	○
		Fish Tissue (300 mm)	Ingestion	○	○	○	•	•	○	○	○	○	○	○	•	○	○
		Amphibians	Ingestion	•	○	○	○	•	○	○	•	○	○	○	○	○	○
Non-Reservoir Sources (Terrestrial)	→	Soil	Incidental Ingestion	•	•	•	○	•	○	•	•	•	○	○	○	○	•
		Plant Tissues	Ingestion	○	•	•	○	○	○	•	○	○	•	○	○	•	○
		Small Mammals/ Birds	Ingestion	•	○	○	•	•	○	○	○	○	•	○	•	○	○
		Soil Invertebrates	Ingestion	•	○	○	○	•	○	○	•	○	•	○	○	•	•

Note: Methyl mercury concentrations expected to vary in each scenario tested. (Reservoir Sources)

Note: Methyl mercury concentrations are expected to remain constant in each scenario tested. (Non-Reservoir Sources)

Note: solid bullets indicate pathways that are likely to be operational; solid bullets with a star indicate an open pathway, but almost negliglible consumption.

Figure 3.4.1 Comparison of dose and expected effect on bird offspring production for the Site C - Peak and Peace – Baseline scenarios.

The left vertical solid red lines are equal to background dose, while the right dashed vertical lines are equal to estimated Site C - Peak dose. For Canada goose the lines are almost identical and are therefore indistinguishable. The blue solid line is an empirically fit dose-response curve.

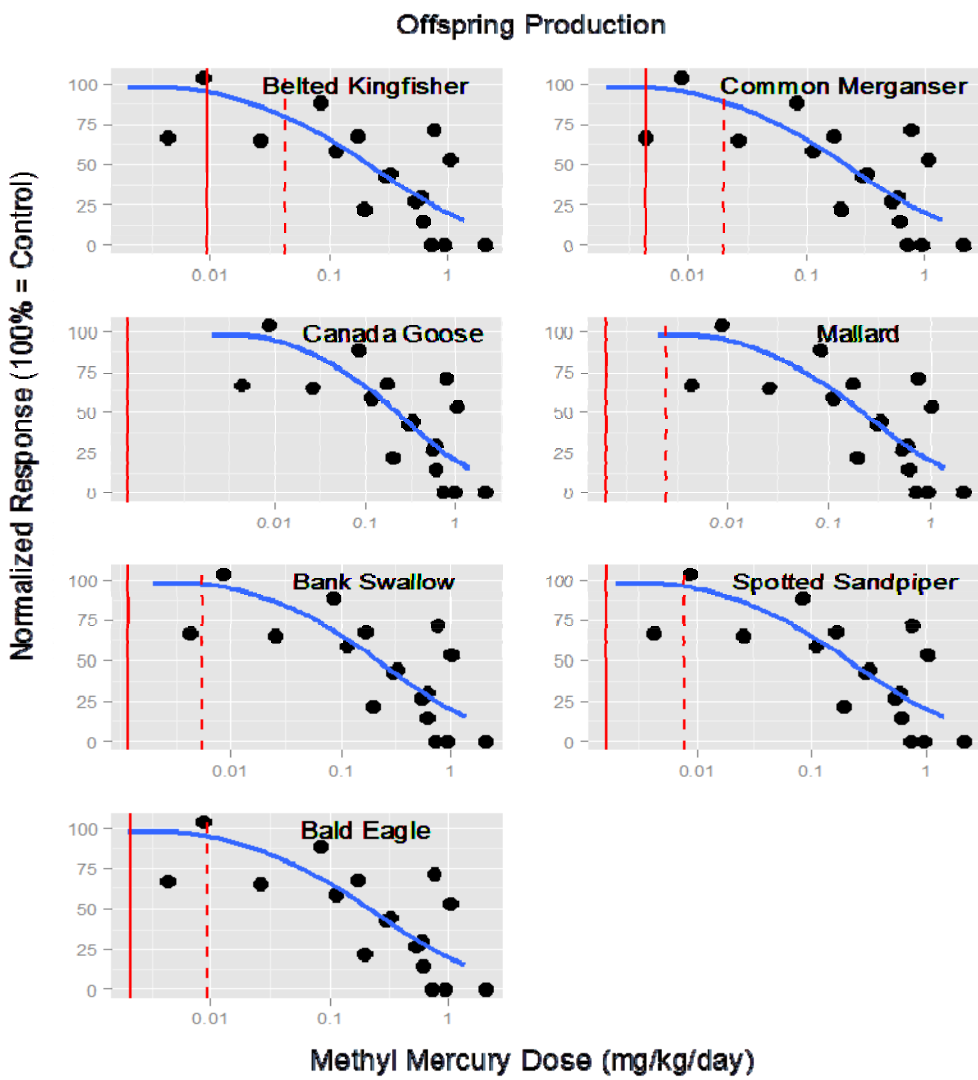
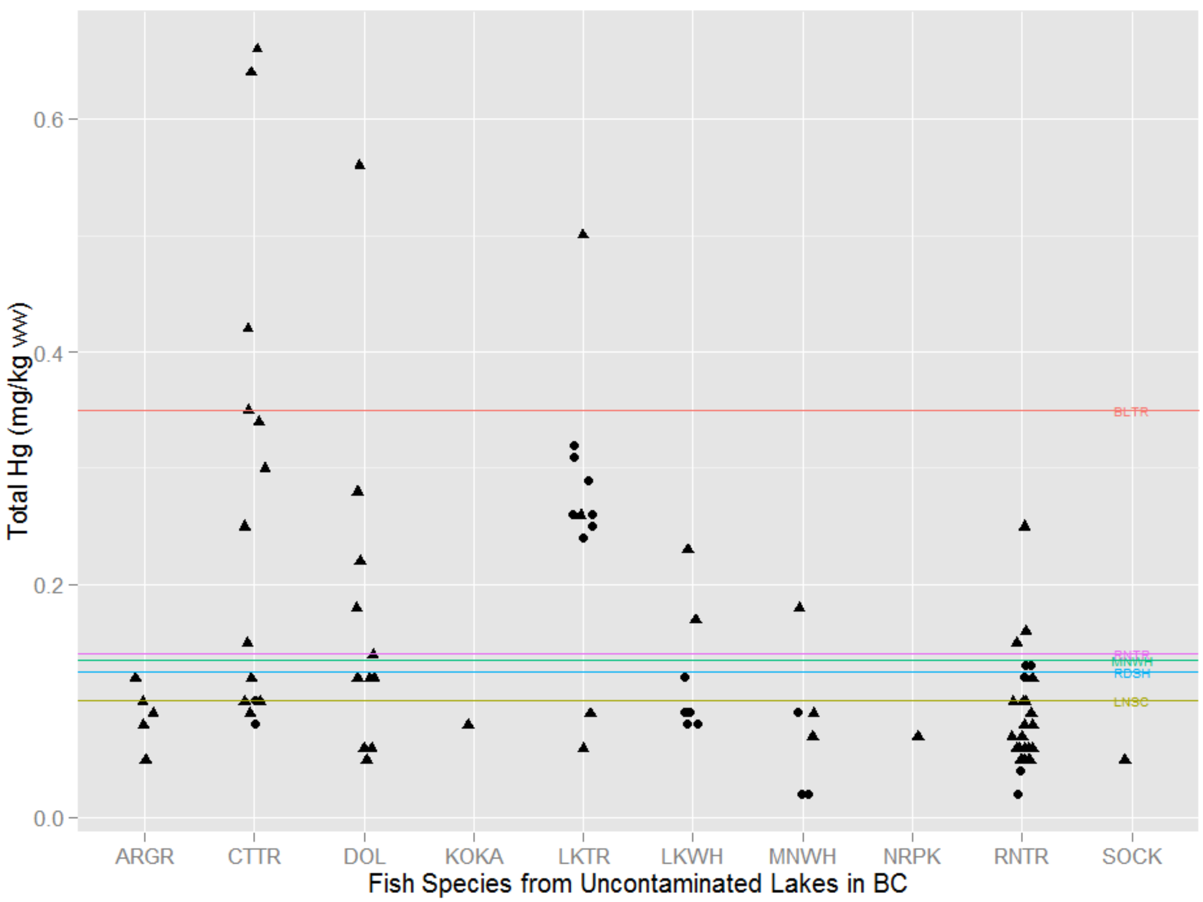


Figure 3.4.2 Predicted peak mercury concentrations in Site C fish relative to measured mercury concentrations in fish from uncontaminated lakes in British Columbia (Rieberger 1992, Baker 2002).



APPENDIX A – Glossary of Terms

acceptable effect level (AEL)	The magnitude (or rate) of effects that would be acceptable for a specific measurement endpoint or assessment endpoint. The AEL operationalizes a protection goal.
assessment endpoint	An assessment endpoint is an explicit expression of the environmental value to be protected. An assessment endpoint must include an entity (typically a receptor or receptor group – i.e., a 'thing' to be protected) and a specific property of that receptor (an attribute). For example, if the entity is a fish community, attributes could include the number of species, the trophic structure, etc. An assessment endpoint may also have an explicit spatial or temporal component.
background	A single value representing the representative background concentration of a criteria air contaminant
baseline	Conditions, in terms of ambient concentrations, associated with existing sources in the study area, including all human-caused and natural sources
benthos	The collection of organisms that live on or in the bottom of a body of water
bioaccumulation factor (BAF)	The quotient obtained by dividing the concentration of a substance in an organism (or specified tissue) by its concentration in a specified exposure medium, for example, air, food, sediment, soil, water (definition from ASTM 2011).
bioaccumulation	The progressive accumulation of a substance in a living organism above a background concentration. This occurs as a result of its intake from food and also directly from the environment via water or sediment. Methylmercury is known as a bioaccumulative substance, whereas inorganic mercury is not.
bioavailable	Available for uptake by an aquatic organism
bioconcentration factor (BCF)	Equivalent to an uptake factor, for the case where water (only) is the abiotic exposure medium.
biomagnification	The tendency of some chemicals to accumulate or biomagnify at higher concentrations at progressively greater levels or steps up the food web, usually through dietary accumulation
biomass	Weight of organic matter (i.e., plants and animals) in an ecosystem

concentration	A measure of a substance in air, water, soil, or living tissue (the medium), expressed as a mass of substance per volume of medium; amount of a material per unit volume
conceptual site model (CSM)	A narrative and graphical representation of the relationships between contaminant sources, fate, exposure pathways, and receptors.
dose-response	The relationship between an effects measure and exposure (measured as dose) across a range of dose values.
ecological risk assessment (ERA)	The process of evaluating the potential adverse effects on non-human organisms, populations or communities in response to human-induced stressors. ERA entails the application of a formal framework, analytical process, or model to estimate the effects of human actions on natural organisms, populations or communities and interprets the significance of those effects in light of the uncertainties identified in each study component.
effect size	The absolute or relative magnitude of response to a stressor for a measurement endpoint.
effects assessment	For any line of evidence, the component of a risk assessment that characterizes the nature of effects elicited by each contaminant under an exposure condition that is relevant to each receptor of concern.
exposure assessment	For any line of evidence, the component of a risk assessment that quantifies the degree to which an organism encounters a stressor.
exposure pathways	The routes through which a receptor of concern encounters COCs in environmental media (e.g., soil, water, air, sediment). Examples of exposure pathways include ingestion and inhalation.
exposure point concentration	The value that represents a conservative estimate of the chemical concentration or dose available to an organism from a route of exposure.
extrapolation	Inference or estimation by extending or projecting known information to a domain (spatial, temporal, biological, or chemical) that has not yet been studied. In statistics, extrapolation entails estimation (of a value of a variable outside

	a known range) from values within a known range, and requires an assumption that the estimated value follows logically from the known values.
feeding guild	A group of organisms that use the same ecological resource in a similar way for feeding (e.g., insectivores, granivores, detritivores, carnivores); or, a group of species that overlap significantly in their niche requirements.
hazard quotient (HQ)	A numerical ratio that divides an estimated environmental concentration or other exposure measure by a response benchmark. Typically the response benchmark is a value assumed to be protective of the receptor of concern. HQ values below one (1.0) indicate negligible potential for harm, whereas HQ values above one indicate that an adverse response is possible and that more precise or accurate evaluation of risks may be warranted to address uncertainty.
inorganic mercury	Mercury that is associated with other compounds or elements other than carbon, such as chlorine, sulphur, silver, gold, or oxygen. Elemental mercury is also a form of inorganic mercury
likelihood	In common usage, synonymous with the probability or frequency of an event. In statistical usage, likelihood is distinguished from probability, and refers to the estimation of unknown parameters based on known outcomes.
line of evidence (LOE)	Any pairing of exposure and effects measures that provides evidence for the evaluation of a specific assessment endpoint. Typically a line of evidence requires use of one or more measurement endpoints. If the focus of the LOE is an effects measure (e.g., a toxicity test), the paired exposure measure may be quantitative (e.g., contaminant concentrations) or categorical (e.g., on-site versus a reference condition).
littoral	Inhabiting or being situated in shoreline aquatic habitat having a water depth generally <6 m

lowest-observed-adverse-effect level (LOAEL) – Lowest amount, dose, or concentration of an agent, found by experiment or observation, that causes an adverse alteration of morphology, functional capacity, growth, development or life span in an organism, system, or (sub)population. Methods vary for identifying a LOAEL, but often apply statistical significance as a criterion.

measurement endpoint	A measurement endpoint is a parameter that measures or describes exposure of, or an effect on, a receptor of concern. Alternatively, the term describes a change in an attribute of an assessment endpoint (or its surrogate) in response to a stressor to which it is exposed.
mercury	The general term used to describe the element mercury (Hg). Mercury can exist in many forms. In the context of the Site C EIS, mercury refers to any form of mercury that is found in water, sediment, soil, vegetation, and animal tissue, including invertebrates and fish, either as inorganic mercury bound to other elements (e.g., carbon, sulphur) or as methylmercury.
methylation	The process by which inorganic mercury is transformed into methylmercury, usually mediated by sulphur-reducing bacteria in sediments. This natural process is accelerated in new reservoirs or impoundments.
methylmercury	This is the 'organic' form of mercury or CH3-Hg+ whereby a mercury atom is attached to a carbon via a methyl group. This is the most toxic form of mercury and is the form that is easily absorbed and accumulated by aquatic organisms. Methylmercury typically comprises about 95% of the total mercury concentration that is present in fish.
model	A simplified description of a system, theory, or phenomenon that accounts for its known or inferred properties and that may be used for further study of its characteristics. In all cases, a model is a simplification of a more complex system, and the details not represented by the model structure are considered to be errors/variations not central to the problem at hand. Models include statistical models (numerical processes used to simulate or approximate complex processes) and conceptual models (graphical or schematic representation of key processes and pathways).
omnivore	An organism that has a varied diet, consuming a variety of food items including algae, invertebrates and, sometimes, fish to acquire energy; an example is a sucker or whitefish
piscivore	An organism that primarily consumes fish to acquire energy; an example is an adult lake trout or bull trout

point estimate	A single numerical value used to represent the state of a random variable. A point estimate collapses (or ignores) all of the variability and incertitude regarding a parameter or variable.
probability	A mathematical way of expressing knowledge or belief that an event or outcome will occur or has occurred. In statistical usage, probability is distinguished from likelihood, and refers to the prediction of unknown outcomes based on known parameters.
protection goal	A narrative statement that defines the desirable level of protection for a receptor or receptor group (see also acceptable effect level).
qualitative	Adjective describing an approach that is narrative, referring to the characteristics of something being described, rather than numerical measurement.
quantitative	Adjective describing an approach that is numerical (applies mathematical scores, probabilities, or parameters) in the derivation or analysis of risk estimates.
receptor of concern (ROC)	In ERA, any non-human individual organism, species, population, community, habitat or ecosystem that is potentially exposed to contaminants of concern and that is considered in the ERA. Identification of an organism as an ROC does not mean that it is being harmed, only that a pathway exists such that there is potential for harm.
reference (condition)	A location, group of locations, or experimental treatment designed to reflect the ambient physical and chemical conditions of a contaminated medium or location in the absence of the stressors of concern in the risk assessment. For example, in a study of soil contamination, the reference condition should reflect the climate, substrate, and habitat factors relevant to the site but with no incremental contamination relative to background conditions
regression	A form of statistical modeling that attempts to evaluate the numerical relationship between one variable (termed the dependent variable) and one or more other variables (termed the independent variables).
RESMERC	The Reservoir Mercury model developed by Reed Harris Environmental Inc. of Oakville, Ontario. This is a mechanistic

	model developed to predict concentrations of methylmercury in environmental media in newly formed reservoirs.
response profile	The relationship between COC concentrations and ecological effects.
risk characterization	The process of estimating the magnitude (and where relevant, the probability) of adverse ecological impacts based on the information obtained from the exposure and effects assessments. Risk characterization also translates complex scientific information into a format that is useful for risk managers, by conveying the ecological consequences of the risk estimates along with the associated uncertainties.
sediment	Material consisting of small particles (such as sand or mud), that are suspended in or settle to the bottom of a liquid; sediment input into a water body comes from natural sources (such as erosion of soils or rock), or as a result of anthropogenic activities (such as forestry, agriculture, or construction activities); certain types of contaminants will collect on and adhere to sediment particles
sensitivity	The quality of being able to reliably detect perturbations in a parameter.
stressor	any substance or process that may cause an undesirable response to the health or biological status of an organism.
surrogate ROC	a surrogate ROC that is representative of a receptor type (e.g., a shrew may be used as a surrogate ROC for insectivorous mammals). More than one surrogate ROC may be used to represent a particular receptor type.
temporal	Relating to time, particularly in terms of changes or variations observed over a time period of interest.
total mercury	The sum of all forms of mercury analysed in any environmental media, a combination of organic and inorganic mercury
toxicity reference value (TRV)	An exposure concentration or dose that is not expected to cause an unacceptable level of effect in receptor(s) exposed to the contaminant of potential concern. A TRV is a specific type of threshold, as defined above.
toxicity	The observation of a chemically-induced physiological or biological response that impairs the health of an organism.

uncertainty	Uncertainty is a term used in subtly different ways in a number of scientific fields. Generally, it refers to imperfect knowledge regarding a given parameter, process, or condition. In risk assessment, uncertainty is the state of having limited knowledge where it is impossible to exactly describe an existing state or future outcome. Uncertainties come in many forms, including measurement uncertainty, random variations, conceptual uncertainty, and ignorance.
uptake factor	A factor used to extrapolate contaminant concentrations from a single abiotic exposure medium to a tissue concentration in an organism. Several types of uptake factors exist, including the BCF, BAF, and BSAF.
watershed	The entire geographical area drained by a river and its tributaries
weight	The degree of emphasis placed on a finding or line of evidence relative to others. The weight is a function of the overall value (information, reduction of uncertainty) in terms of addressing an assessment endpoint, and is determined by assessing the attributes relevant to the study.
weight-of-evidence (WOE)	A systematic procedure used to aggregate or synthesize a number of different types of evidence, with the objective of developing a single unified conclusion or explanation to an environmental characterization. WOE is one of the tools applied during the risk characterization stage of ERA.
wetland	An area of land where the water table is at, near or above the surface, or which is saturated for long enough periods of time to promote features such as water-tolerant vegetation
wildlife	In the context of ERA, the term is generally applied to birds and mammals, and sometimes defined to include reptiles and amphibians. Generally it excludes fish and invertebrates.
zooplankton	Invertebrates that live in the water column of lakes and reservoirs and large rivers and do not use bottom habitat

APPENDIX B – Food Chain Model Equations and Inputs

B1. Food Chain Model Equations

This section summarizes the equations used in the food chain model.

1. **Food Ingestion Rates** – In cases where primary literature values were not available, food ingestion rates (*FI*, kg dw/kg ww/day) are estimated using allometric equations described in Nagy (1987) based on individual feeding guilds, i.e.,

$$FI = a \times BW^b \qquad \text{(Eq. 1)}$$

Where:

BW represents the organism's mean body weight (g, ww)

a and *b* are constants specific to various groups of terrestrial vertebrates

These dry weight food ingestion rates were then converted into wet weights (I_F, kg ww/kg ww/day) following equation 2:

$$I_F = FI \big/ (1 - moist\_diet) \qquad \text{(Eq. 2)}$$

Where:

moist_diet (unitless fraction) represents the weighted average moisture content in the diet of the animal, based on measured contents in tissues from the site or values from the literature in some cases.

2. **Soil Ingestion Rates** – Soil and sediment ingestion rates (I_S, kg dw/kg ww/day) are based on an estimated fraction of incidental ingestion during foraging activities. They are derived from the food ingestion rate according to:

$$I_S = FI \times \phi \qquad \text{(Eq. 3)}$$

Where:

FI (kg dw/kg ww/day) is the dry food ingestion rate

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ϕ is the fraction of incidental soil or sediment ingested during feeding.

3. **Drinking Water Ingestion Rates** – Drinking water ingestion rates (I_W, L/kg ww/day) were based on primary literature, or when values were unavailable they were estimated based on the following Nagy (1987) allometric equation:

$$I_W = a \times BW^b \quad \text{(Eq. 4)}$$

Where:

BW (kg, ww) represents the organism's mean body weight

a (L/kg*kg/day) and *B* (unitless) are constants specific to various groups of terrestrial vertebrates

4. **Dose From Food -** An intake dose of contaminants from food (D_F, mg/kg·bw/day) was determined from the dietary concentration following:

$$D_F = I_F \times \sum_1^j \left(C_{Fj} \times p_{Fj}\right) \quad \text{(Eq. 5)}$$

Where:

I_F (kg ww/kg bw/day) represents the feeding ingestion rate

C_{Fj} (mg/kg ww) represents the COPC concentration in prey item *j* in the diet of the ROC (95% UCLM or maximum or weighted average)

p_{Fj} (unitless) represents the proportion of prey item *j* in the diet of the predator

5. **Dose From Soil Intake** (primarily terrestrial foragers) - The total dose from incidental ingestion of COPC contaminated soil (D_S, mg/kg·bw/day) was calculated using the following equation:

$$D_S = I_S \times C_S \qquad \text{(Eq. 6)}$$

Where:

I_S (kg ww/kg bw/day) represents the ingestion rate of sediment

C_S (mg/kg dw) represents the COPC concentration in ingested sediment

6. **Dose From Drinking Water** – The total dose from drinking water ingestion of COPCs (D_W, mg/kg·bw/day) was calculated using the following equation:

$$D_W = I_W \times C_W \qquad \text{(Eq. 8)}$$

Where:

I_W (L/kg bw/day) represents the drinking water ingestion rate

C_W (mg/L) represents the COPC concentration in the water

7. **Total Unadjusted Dose -** The unadjusted dose (D_{UT}, mg/kg ww/day) was calculated by taking the sum of the doses for the separate media: food, soil, water:

$$D_{UT} = D_F + D_S + D_W \qquad \text{(Eq. 9)}$$

Where:

D_F (mg/kg wet/day) is the dose from food

D_S (mg/kg wet/day) is the dose from soil

D_W (mg/kg wet/day) is the dose from water

8. **Dose Adjustment Factor -** The dose adjustment factor was calculated as a function of territory/foraging range, habitat quality, and bioavailability of the COPCs.

$$DAF = FRF \times \alpha \qquad \text{(Eq. 10)}$$

Where:

FRF (unitless) is the foraging range factor, which represents the surface area of the environmental issue (i.e., mine property site) that overlaps with the territory or foraging range of the species.

α (unitless) is the dietary uptake efficiency of a given chemical and can be thought of as the proportion of chemical that is absorbed through the intestinal tract compared to the total amount ingested. The value does not account for difference in availability between soil and different food types.

9. **Total Adjusted Dose** – The total adjusted dose (D_{AT}, mg/kg wet/day) was then calculated by multiplying the unadjusted dose and the dose adjustment factor:

$$D_{AT} = D_{UT} \times DAF \qquad \text{(Eq. 11)}$$

Where:

D_{UT} is the unadjusted total dietary dose of a given chemical (mg/kg wet/day)

DAF is the dose adjustment factor (unitless)

10. **Hazard Quotient (HQ)** – The hazard quotient (*HQ*, unitless) is calculated by dividing the adjusted dose by the TRV.

$$HQ = {}^{D_{AT}}\!/_{TRV} \qquad \text{(Eq. 12)}$$

Where:

D_{AT} is the adjusted total dietary dose of a given chemical (mg/kg wet/day)

TRV is the toxicity reference value (mg/kg ww/day).

B2. Food Chain Model Inputs

The following input parameters were required for the food chain model:

1. Methylmercury concentrations in dietary items, water, soil, and sediment (exposure concentrations) – **Section B2.1**
2. Ingestion rates for food, water, soil, and sediment – **Section B2.2**
3. Dietary preferences for each ROC – **Section B2.3**
4. Foraging range for each ROC – conservatively assumed to be within the Site C area (i.e., reservoir footprint and adjacent terrestrial habitats [as appropriate for each ROC])
5. Methylmercury bioavailability (i.e., absorption efficiency in the gut) – assumed to be 100%

Data inputs and sources for: (1) exposure concentrations; (2) ingestion rates; and (3) dietary preferences are summarized below and provided in more detail in **Tables 3.2.1, 3.2.2 and 3.2.3 of the Main Report**. Regarding foraging range (4), terrestrial wildlife are assumed to spend 100 percent of their time foraging locally along and upland of the Site C reservoir, and aquatic wildlife are assumed to spend 100 percent of their time foraging within the Site C reservoir footprint. Regarding absorption (5), dietary uptake efficiency is often very high for methylmercury (likely > 80%). For the purpose of risk estimation, this factor was conservatively assumed to be 1 (i.e., 100% of ingested methylmercury is absorbed by the gastrointestinal tract).

B2.1 EXPOSURE CONCENTRATIONS

Depending on the scenario, data for exposure concentrations were obtained from the following: (1) chemistry data specific to an exposure media, (2) chemistry data and/or RESMERC data used as a surrogate for another related media (surrogate data), (3) Bioconcentration Factor (BCF) or Bioaccumulation Factor (BAF) predictions using chemistry data and RESMERC data, or (4) RESMERC data. These are summarized below, further details are provided in **Table 3.2.1 of the Main Report**. Importantly, methylmercury concentrations in terrestrial media (i.e., soils, plants, ground insects, small mammals, and birds) are expected to remain the same for current (Baseline) and future (Site C) scenarios.

Chemistry Data – Actual measured chemistry data (including soil, shrubs/trees and grasses/herbs) for exposure media from the Peace River within the future reservoir footprint. These data were obtained from Azimuth 2011 and used for the Peace River Baseline Scenario. Chemistry data were used as follows:

Soil, shrubs/tree, grasses/herbs: Where the number of samples was greater than or equal to five, a 95 percent upper confidence limit of the mean (UCLM) was calculated using ProUCL (Version 4.0) to obtain a conservative estimate of the average exposure concentration. Where the number of samples was less than five, than the maximum concentrations was used to estimate exposure concentrations (exceptions to this [grasses and herbs] are described in **Table 3.2.1 of the Main Report**).

Surrogate Data – Surrogate data are measured chemistry data (collected from the Peace River within the future reservoir footprint) or RESMERC data measured/predicted for a specific exposure media and then applied as a surrogate to other related media. These include the following:

- Soil and plant tissue data for the Peace River Baseline scenario were used as surrogate data for the remaining three scenarios, on the assumption that exposure concentrations for these media will be similar around the upland of the Site C reservoir footprint, once the dam is constructed.
- Flying insect tissue concentrations for all four scenarios were estimated using 50 percent ground insect tissue concentrations (from chemistry data) and 50 percent flying insect tissue concentrations (RESMERC data).
- The methylmercury tissue concentration for the smallest size rainbow trout (age class 0+ [16.5 to 162.8 mm]) obtained from RESMERC was used as a surrogate for amphibian tissue due to some similarities in diet; the rainbow trout feeds in part on terrestrial insects while the western toad feeds largely on terrestrial insects. This is not ideal,

terrestrial invertebrates are expected to be less exposed to methylmercury than aquatic ones.

Bioconcentration Factor and Bioaccumulation Factors - Predicted Data

Small mammal, ground insect, and earthworm tissue concentrations for all four scenarios were estimated using BAFs for methylmercury obtained from the literature, as follows:

- The small mammal BAF (3.25) is from an Uptake Factor (UF) model (whole body milligram//kilogram dry weight = UF · soil milligram/kilogram dry weight) based on a terrestrial field study with Roe deer (Gnamus and Horvat, 1999).
- The earthworm and ground insect BAF (8) is from an Uptake Factor model, estimated (90th percentile) based on a comprehensive data set of 25 paired soil/earthworm samples developed by Allard et al. (2003). This work was completed at staffed light stations on behalf of the Canadian Coast Guard Pacific Region.

Aquatic plant tissue concentrations for the four scenarios were estimated using (1) a BCF for total mercury, (2) total unfiltered mercury water concentrations obtained from RESMERC for each of the four scenarios, and (3) the assumption that methylmercury is approximately 36 percent of total mercury in aquatic plants (Moore et al. 1995). A BCF of 7,000 was derived from Canadian field studies reporting total mercury concentrations in macrophyte tissue and water (i.e., concentration in tissue [wet weight]-water concentration); unusually high and low BCFs were discounted.

Using this approach, the estimated total and methylmercury concentrations in aquatic plant tissue for the Baseline Peace River Scenario was calculated to be 0.0052 and 0.0019 milligram/kilogram wet weight, respectively. To put the estimates in context, the estimates were converted to dry weight and nanograms/gram (using an 87 percent moisture concentration obtained from USEPA 1993) and compared to concentrations summarized by Moore et al. 1995. The estimated total mercury concentration (40 nanogram/gram dry weight) fell well within the range of mercury concentrations reported by Moore et al. 1995 in Figure 1 (approximately 10 to 100 nanogram/gram dry weight from areas of no known mercury point source). The estimated methylmercury concentration (14.4 nanogram/gram dry weight) was around two times higher than the maximum concentration from the experimental lakes area (estimated from Figure 2 in Moore et al. 1995 to be approximately 7 nanogram/gram dry weight). Based on the above data, the aquatic plant methylmercury are estimates expected to be conservative.

RESMERC Data – These are modelled predictions of exposure concentrations for water, sediment, aquatic invertebrate and fish concentrations for both baseline and post dam construction. For the baseline scenario, RESMERC predictions were calibrated to approximate measured chemistry data collected from the Peace River (Azimuth 2011) as closely as possible. Data from RESMERC (Harris and Hutchinson 2013) are summarized in **Appendix E** and were used as follows:

Water – Water concentrations for all four scenarios were based on modelled predictions of water concentrations (RESMERC, Harris and Hutchinson 2013) for upstream and downstream reaches. Only concentrations predicted for the epilimnion were used, water from the hypolimnion was not considered accessible as drinking water to wildlife. Methylmercury concentrations were area weighted for upstream and downstream reaches to provide one estimate for each scenario.

Sediment – Sediment concentrations for all four scenarios were based on modelled predictions of sediment concentrations (RESMERC, Harris and Hutchinson 2013) for upstream and downstream reaches including original riverbed sediments, flooded uplands and flooded wetlands. Only concentrations predicted for the epilimnion were used, sediment from the hypolimnion was not considered accessible to wildlife. Methylmercury concentrations were area weighted for upstream and downstream reaches to provide one estimate for each scenario.

Aquatic Invertebrates (for receptors which feed from the water column/sediments) – Invertebrate concentrations for all four scenarios were based on modelled predictions of invertebrate concentrations (RESMERC, Harris and Hutchinson 2013) for both benthos (sediment-associated invertebrates) and water-column invertebrates. For benthos, concentrations used in the model were estimated based on upstream and downstream reaches, including original riverbed sediments, flooded upland and flooded wetlands. Only concentrations predicted for the epilimnion were used, invertebrates from the hypolimnion were not considered accessible to wildlife. Benthos and water-column invertebrate concentrations were each separately area weighted for upstream and downstream reaches and then combined using a 50/50 ratio to provide one estimate for each scenario. Where necessary, concentrations were converted from dry to weight wet using an 89% moisture concentration to be consistent with moisture concentrations used in RESMERC for aquatic invertebrates.

Aquatic Invertebrates (for calculation of flying invertebrate concentrations) – Invertebrate concentrations for the estimation of flying insect concentrations were calculated as above; however, both epilimnion and hypolimnion benthos concentrations were used. A portion of the benthos from the hypolimnion is expected to emerge and take on a terrestrial flying insect phase.

Fish Data – The bull trout, rainbow trout, longnose sucker, and redside shiner were chosen for inclusion as representative fish species likely to compose the majority of wildlife fish dietary component (**see Section 2-4**). For each of these species, RESMERC predicted methylmercury concentrations and predicted biomass for each age class for each of the four scenarios. Within the food chain model, the following assumptions were made:

- Fish eating receptors were assumed to target specific fish sizes as follows:
    - The belted kingfisher was assumed to eat smaller fish up to 120 mm (Hamas 1994). The common merganser was also assumed to eat mostly smaller fish.
    - The American mink and northern river otter were assumed to eat fish up to 300 mm (Reed et al. 1994, Melquist and Dronkert 1987, Cote et al. 2008).
    - The bald eagle was also assumed to eat fish up to 300 mm, with some larger fish (up to 500 mm) eaten opportunistically.
- In the absence of data to suggest otherwise, fish eating receptors were assumed to be eating all four fish species within the target size class at proportions equal to their

respective biomass (i.e., receptors will eat more of abundant fish within the targeted size range).

For the food chain model, an average methylmercury concentration was calculated for each fish size class (< 120 mm, < 300 mm, < 500 mm), including all four species. Concentrations were biomass weighted to proportionally represent fish species and age class abundance (biomass was estimated from RESMERC). As fish were sorted into size classes based on estimated size ranges in fish age classes, the demarcation between the fish size classes is approximate (i.e., there is a degree of overlap between size classes; sizes within some fish age classes spanned two fish size classes). Overall, differentiating fish size in the diet is expected to have relatively minor effects on total dose in the food chain model, particularly for the larger fish size classes, as the Site C reservoir is expected to be dominated by relatively smaller redside shiners and longnose suckers (< 200 mm for redside shiner and < 300 mm for longnose suckers) (based on biomass estimates from RESMERC).

B2.2 INGESTION RATES

Ingestion rates (**Table 3.2.2 of the Main Report**) were obtained from key secondary and primary literature.

Food ingestion rates of wildlife ROCs were based on species-specific literature derived values where available (e.g., USEPA 1993; Sample et al. 1997, EC 2012a). In the absence of literature values, rates were estimated using allometric equations reported in USEPA 1993 (from Nagy 1987) for individual feeding guilds (**Equation 1** in **Appendix B1**). Dry weight food ingestion rates were then converted into wet weights using the weighted average moisture content in the diet of the ROC, measured in tissues from the site (**Equation 2** in **Appendix B1**), or estimated from the literature.

It was assumed that soil would be ingested incidentally (e.g., adhering to food) by wildlife feeding in the terrestrial environment. Soil ingestion rates were primarily calculated following the approach presented in USEPA (1993). This approach uses a percentage of the dry weight food ingestion rates to represent the amount of incidental soil ingested during feeding (**Equation 3** in

Appendix B1). Soil ingestion percentages have been compiled for numerous species by USEPA (1993). However, some of the receptor species chosen for the site's model were not included. In this case, an appropriate value based on similarities in feeding behaviour between species was selected. Where substitutions did not appear suitable, alternative sources of soil ingestion were investigated (e.g., Oak Ridge National Laboratory documents such as Sample and Suter 1994 and Efroymson et al. 1997a). Rates ranged from 0 to 10 percent of the dry food ingestion rates (see **Appendix B1**).

Drinking water ingestion rates of wildlife ROCs were based on species-specific literature derived values where available. Otherwise, they were estimated using allometric equations reported in USEPA 1993 (from Nagy 1987) and EC 2012a for specific feeding guilds (**Equation 4** in **Appendix B1**).

B2.3 DIETARY PREFERENCES

Dietary preferences (**Table 3.2.3 of the Main Report**) were obtained from key secondary and primary literature.

In addition to the ingestion rate and concentration of methylmercury in a food item, the calculated dose is a function of the dietary preferences (*j*, percent prey item) of the animal. The proportion of a given food type in the diet is multiplied by the measured concentration giving a measure of how much a single food item contributes to the overall dose.

Dietary preferences were determined for each ROC based on information gathered from the literature (**Table 3.2.3 of the Main Report**). While a wide variety of food items were collected to support the risk assessment (Azimuth 2011), the diet of most wildlife species differs depending on geographical location and/or season. The approach adopted in this WRA was to develop an approximation of the general feeding behaviour of the species, particularly during early development life stages (e.g., feeding of fledglings/juveniles).

APPENDIX C – Food Chain Model Outputs

Table C1 Risk assessment summary for the American beaver

	Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		1.99E-07	1.99E-07	1.99E-07	1.99E-07
	Shrubs/Trees	0.70	0 (59%ofTotalDose)	0 (56%ofTotalDose)	0 (57%ofTotalDose)	0 (60%ofTotalDose)
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Onsite Food		1.22E-04	1.22E-04	1.22E-04	1.22E-04
	Total Onsite Dose		1.22E-04	1.22E-04	1.22E-04	1.22E-04
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0.70	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		9.16E-07	1.11E-05	7.93E-06	9.52E-07
	Water		1.52E-09	2.65E-09	2.35E-09	1.55E-09
	Aquatic plants	0.30	0 (40%ofTotalDose)	0 (39%ofTotalDose)	0 (39%ofTotalDose)	0 (40%ofTotalDose)
	Aquatic inverts	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		8.38E-05	8.57E-05	8.32E-05	8.07E-05
	Total Aquatic Onsite Dose		8.47E-05	9.68E-05	9.11E-05	8.17E-05
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0.30	0	0	0	0
	Aquatic inverts 1	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			2.07E-04	2.19E-04	2.13E-04	2.04E-04

Table C2 Risk assessment summary for the moose

	Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		9.80E-08	9.80E-08	9.80E-08	9.80E-08
	Shrubs/Trees	0.80	0 (71%ofTotalDose)	0 (67%ofTotalDose)	0 (69%ofTotalDose)	0 (72%ofTotalDose)
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Onsite Food		6.38E-05	6.38E-05	6.38E-05	6.38E-05
	Total Onsite Dose		6.39E-05	6.39E-05	6.39E-05	6.39E-05
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0.80	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		4.50E-07	5.46E-06	3.90E-06	4.68E-07
	Water		1.03E-09	1.79E-09	1.60E-09	1.05E-09
	Aquatic plants	0.20	0 (28%ofTotalDose)	0 (27%ofTotalDose)	0 (27%ofTotalDose)	0 (28%ofTotalDose)
	Aquatic inverts	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		2.55E-05	2.61E-05	2.54E-05	2.46E-05
	Total Aquatic Onsite Dose		2.60E-05	3.16E-05	2.93E-05	2.51E-05
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0.20	0	0	0	0
	Aquatic inverts 1	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			8.99E-05	9.55E-05	9.32E-05	8.90E-05

Table C3 Risk assessment summary for the muskrat

	Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	1.00E-2	1.22E-06	1.22E-06	1.22E-06	1.22E-06
	Earthworms	5.00E-3	7.54E-07	7.54E-07	7.54E-07	7.54E-07
	Ground Insects	5.00E-3	1.65E-06	1.65E-06	1.65E-06	1.65E-06
	Flying Insects	0	0	0	0	0
	Total Onsite Food		3.63E-06	3.63E-06	3.63E-06	3.63E-06
	Total Onsite Dose		3.63E-06	3.63E-06	3.63E-06	3.63E-06
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	1.00E-2	0	0	0	0
	Earthworms	5.00E-3	0	0	0	0
	Ground Insects	5.00E-3	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		1.58E-06	1.91E-05	1.37E-05	1.64E-06
	Water		2.06E-09	3.59E-09	3.19E-09	2.10E-09
	Aquatic plants	0.80	0.001 (61%ofTotalDose)	0.001 (23%ofTotalDose)	0.001 (25%ofTotalDose)	0.001 (57%ofTotalDose)
	Aquatic inverts	0.15	0 (14%ofTotalDose)	0.001 (36%ofTotalDose)	0.001 (34%ofTotalDose)	0 (14%ofTotalDose)
	Amphibians	1.00E-2	8.84E-05	0 (13%ofTotalDose)	0 (12%ofTotalDose)	9.48E-05
	Fish (< 120 mm)	0.02	0 (17%ofTotalDose)	0.001 (28%ofTotalDose)	0.001 (28%ofTotalDose)	0 (21%ofTotalDose)
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		1.18E-03	3.20E-03	2.82E-03	1.20E-03
	Total Aquatic Onsite Dose		1.18E-03	3.22E-03	2.83E-03	1.20E-03
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0.80	0	0	0	0
	Aquatic inverts 1	0.15	0	0	0	0
	Amphibians	1.00E-2	0	0	0	0
	Fish (< 120 mm)	0.02	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			1.18E-03	3.22E-03	2.83E-03	1.21E-03

Table C4 Risk assessment summary for the northern river otter

Media		Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0.05	1.72E-06	1.72E-06	1.72E-06	1.72E-06
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Onsite Food		1.72E-06	1.72E-06	1.72E-06	1.72E-06
	Total Onsite Dose		1.72E-06	1.72E-06	1.72E-06	1.72E-06
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0.05	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		6.76E-07	8.20E-06	5.85E-06	7.02E-07
	Water		1.67E-09	2.90E-09	2.58E-09	1.70E-09
	Aquatic plants	0	0	0	0	0
	Aquatic inverts	0.15	4.76E-05	3.27E-04	2.70E-04	4.70E-05
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0.80	0.003 (98%ofTotalDose)	0.013 (97%ofTotalDose)	0.011 (98%ofTotalDose)	0.004 (99%ofTotalDose)
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		2.95E-03	0.013	0.012	3.62E-03
	Total Aquatic Onsite Dose		2.95E-03	0.013	0.012	3.62E-03
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0	0	0	0	0
	Aquatic inverts 1	0.15	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0.80	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			2.95E-03	0.013	0.012	3.62E-03

Table C5 Risk assessment summary for the American mink

Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)					
Soil		0	0	0	0
Shrubs/Trees	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0
Small animals	0.30	1.07E-05	1.07E-05	1.07E-05	1.07E-05
Earthworms	0.05	2.20E-06	2.20E-06	2.20E-06	2.20E-06
Ground Insects	0.05	4.80E-06	4.80E-06	4.80E-06	4.80E-06
Flying Insects	0	0	0	0	0
Total Onsite Food		1.77E-05	1.77E-05	1.77E-05	1.77E-05
Total Onsite Dose		1.77E-05	1.77E-05	1.77E-05	1.77E-05
Offsite Dose (mg/kg wet/day)					
Soil		0	0	0	0
Shrubs/Trees	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0
Small animals	0.30	0	0	0	0
Earthworms	0.05	0	0	0	0
Ground Insects	0.05	0	0	0	0
Flying Insects	0	0	0	0	0
Total Offsite Food		0	0	0	0
Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)					
Sediment		7.60E-07	9.22E-06	6.58E-06	7.90E-07
Water		6.19E-10	1.08E-09	9.58E-10	6.29E-10
Aquatic plants	0	0	0	0	0
Aquatic inverts	0.10	3.28E-05	2.26E-04	1.87E-04	3.25E-05
Amphibians	0.15	0 (22%ofTotalDose)	0.002 (23%ofTotalDose)	0.002 (22%ofTotalDose)	0 (20%ofTotalDose)
Fish (< 120 mm)	0	0	0	0	0
Fish (< 300 mm)	0.35	0.001 (75%ofTotalDose)	0.006 (74%ofTotalDose)	0.005 (75%ofTotalDose)	0.002 (78%ofTotalDose)
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Onsite Food		1.73E-03	7.70E-03	6.84E-03	2.07E-03
Total Aquatic Onsite Dose		1.73E-03	7.71E-03	6.85E-03	2.07E-03
Aquatic Items Offsite (mg/kg wet/day)					
Sediment		0	0	0	0
Water		0	0	0	0
Aquatic plants	0	0	0	0	0
Aquatic inverts 1	0.10	0	0	0	0
Amphibians	0.15	0	0	0	0
Fish (< 120 mm)	0	0	0	0	0
Fish (< 300 mm)	0.35	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Offsite Food		0	0	0	0
Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)		1.75E-03	7.72E-03	6.86E-03	2.08E-03

Table C6 Risk assessment summary for the little brown myotis

	Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	1.00	0.002 (100%ofTotalDose)	0.008 (100%ofTotalDose)	0.007 (100%ofTotalDose)	0.002 (100%ofTotalDose)
	Total Onsite Food		1.70E-03	7.89E-03	6.64E-03	1.92E-03
	Total Onsite Dose		1.70E-03	7.89E-03	6.64E-03	1.92E-03
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	1.00	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		3.36E-09	5.84E-09	5.19E-09	3.41E-09
	Aquatic plants	0	0	0	0	0
	Aquatic inverts	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		0	0	0	0
	Total Aquatic Onsite Dose		3.36E-09	5.84E-09	5.19E-09	3.41E-09
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0	0	0	0	0
	Aquatic inverts 1	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			1.70E-03	7.89E-03	6.64E-03	1.92E-03

Table C7 Risk assessment summary for the Canada goose

Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)					
Soil		2.24E-07	2.24E-07	2.24E-07	2.24E-07
Shrubs/Trees	0.05	7.56E-06	7.56E-06	7.56E-06	7.56E-06
Grasses/Herbs	0.75	0 (77%ofTotalDose)	0 (76%ofTotalDose)	0 (77%ofTotalDose)	0 (77%ofTotalDose)
Small animals	0	0	0	0	0
Earthworms	0	0	0	0	0
Ground Insects	0	0	0	0	0
Flying Insects	0	0	0	0	0
Total Onsite Food		1.94E-04	1.94E-04	1.94E-04	1.94E-04
Total Onsite Dose		1.94E-04	1.94E-04	1.94E-04	1.94E-04
Offsite Dose (mg/kg wet/day)					
Soil		0	0	0	0
Shrubs/Trees	0.05	0	0	0	0
Grasses/Herbs	0.75	0	0	0	0
Small animals	0	0	0	0	0
Earthworms	0	0	0	0	0
Ground Insects	0	0	0	0	0
Flying Insects	0	0	0	0	0
Total Offsite Food		0	0	0	0
Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)					
Sediment		0	0	0	0
Water		9.69E-10	1.68E-09	1.50E-09	9.83E-10
Aquatic plants	0.20	0 (20%ofTotalDose)	0 (20%ofTotalDose)	0 (20%ofTotalDose)	0 (19%ofTotalDose)
Aquatic inverts	0	0	0	0	0
Amphibians	0	0	0	0	0
Fish (< 120 mm)	0	0	0	0	0
Fish (< 300 mm)	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Onsite Food		4.84E-05	4.95E-05	4.80E-05	4.66E-05
Total Aquatic Onsite Dose		4.84E-05	4.95E-05	4.81E-05	4.66E-05
Aquatic Items Offsite (mg/kg wet/day)					
Sediment		0	0	0	0
Water		0	0	0	0
Aquatic plants	0.20	0	0	0	0
Aquatic inverts 1	0	0	0	0	0
Amphibians	0	0	0	0	0
Fish (< 120 mm)	0	0	0	0	0
Fish (< 300 mm)	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Offsite Food		0	0	0	0
Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)		2.42E-04	2.43E-04	2.42E-04	2.41E-04

Table C8 Risk assessment summary for the mallard

Media		Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0.05	2.67E-05	2.67E-05	2.67E-05	2.67E-05
	Small animals	0	0	0	0	0
	Earthworms	1.00E-2	8.71E-07	8.71E-07	8.71E-07	8.71E-07
	Ground Insects	1.00E-2	1.91E-06	1.91E-06	1.91E-06	1.91E-06
	Flying Insects	0.02	8.42E-06	3.91E-05	3.30E-05	9.51E-06
	Total Onsite Food		3.79E-05	6.86E-05	6.24E-05	3.90E-05
	Total Onsite Dose		3.79E-05	6.86E-05	6.24E-05	3.90E-05
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0.05	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	1.00E-2	0	0	0	0
	Ground Insects	1.00E-2	0	0	0	0
	Flying Insects	0.02	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		1.13E-06	1.37E-05	9.75E-06	1.17E-06
	Water		1.24E-09	2.15E-09	1.92E-09	1.26E-09
	Aquatic plants	0.50	0 (42%ofTotalDose)	0 (11%ofTotalDose)	0 (13%ofTotalDose)	0 (40%ofTotalDose)
	Aquatic inverts	0.40	0 (42%ofTotalDose)	0.002 (75%ofTotalDose)	0.001 (73%ofTotalDose)	0 (42%ofTotalDose)
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	1.00E-2	5.75E-05	0 (11%ofTotalDose)	0 (11%ofTotalDose)	0 (12%ofTotalDose)
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		5.78E-04	2.32E-03	1.97E-03	5.80E-04
	Total Aquatic Onsite Dose		5.79E-04	2.33E-03	1.98E-03	5.81E-04
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0.50	0	0	0	0
	Aquatic inverts 1	0.40	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	1.00E-2	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			6.17E-04	2.40E-03	2.04E-03	6.20E-04

Table C9 Risk assessment summary for the bank swallow

Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)					
Soil		6.56E-06	6.56E-06	6.56E-06	6.56E-06
Shrubs/Trees	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0
Small animals	0	0	0	0	0
Earthworms	0	0	0	0	0
Ground Insects	0	0	0	0	0
Flying Insects	1.00	0.001 (99%ofTotalDose)	0.005 (100%ofTotalDose)	0.005 (100%ofTotalDose)	0.001 (100%ofTotalDose)
Total Onsite Food		1.16E-03	5.39E-03	4.54E-03	1.31E-03
Total Onsite Dose		1.17E-03	5.40E-03	4.55E-03	1.32E-03
Offsite Dose (mg/kg wet/day)					
Soil		0	0	0	0
Shrubs/Trees	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0
Small animals	0	0	0	0	0
Earthworms	0	0	0	0	0
Ground Insects	0	0	0	0	0
Flying Insects	1.00	0	0	0	0
Total Offsite Food		0	0	0	0
Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)					
Sediment		0	0	0	0
Water		4.98E-09	8.66E-09	7.70E-09	5.06E-09
Aquatic plants	0	0	0	0	0
Aquatic inverts	0	0	0	0	0
Amphibians	0	0	0	0	0
Fish (< 120 mm)	0	0	0	0	0
Fish (< 300 mm)	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Onsite Food		0	0	0	0
Total Aquatic Onsite Dose		4.98E-09	8.66E-09	7.70E-09	5.06E-09
Aquatic Items Offsite (mg/kg wet/day)					
Sediment		0	0	0	0
Water		0	0	0	0
Aquatic plants	0	0	0	0	0
Aquatic inverts 1	0	0	0	0	0
Amphibians	0	0	0	0	0
Fish (< 120 mm)	0	0	0	0	0
Fish (< 300 mm)	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Offsite Food		0	0	0	0
Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)		1.17E-03	5.40E-03	4.55E-03	1.32E-03

Table C10 Risk assessment summary for the spotted sandpiper

	Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		8.82E-07	8.82E-07	8.82E-07	8.82E-07
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0.25	5.93E-05	5.93E-05	5.93E-05	5.93E-05
	Ground Insects	0.25	1.30E-04	1.30E-04	1.30E-04	1.30E-04
	Flying Insects	0.10	1.15E-04	5.33E-04	4.49E-04	1.30E-04
	Total Onsite Food		3.04E-04	7.22E-04	6.38E-04	3.19E-04
	Total Onsite Dose		3.05E-04	7.23E-04	6.39E-04	3.20E-04
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0	0	0	0	0
	Earthworms	0.25	0	0	0	0
	Ground Insects	0.25	0	0	0	0
	Flying Insects	0.10	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		3.51E-09	6.10E-09	5.43E-09	3.56E-09
	Aquatic plants	0.05	7.08E-05	7.25E-05	7.03E-05	6.82E-05
	Aquatic inverts	0.30	0.001 (33%ofTotalDose)	0.004 (47%ofTotalDose)	0.003 (46%ofTotalDose)	0.001 (30%ofTotalDose)
	Amphibians	0.03	0 (25%ofTotalDose)	0.002 (25%ofTotalDose)	0.002 (25%ofTotalDose)	0 (26%ofTotalDose)
	Fish (< 120 mm)	0.02	0 (19%ofTotalDose)	0.001 (18%ofTotalDose)	0.001 (19%ofTotalDose)	0 (22%ofTotalDose)
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		1.33E-03	7.05E-03	5.99E-03	1.43E-03
	Total Aquatic Onsite Dose		1.33E-03	7.05E-03	5.99E-03	1.43E-03
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0.05	0	0	0	0
	Aquatic inverts 1	0.30	0	0	0	0
	Amphibians	0.03	0	0	0	0
	Fish (< 120 mm)	0.02	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			1.64E-03	7.78E-03	6.63E-03	1.75E-03

Table C11 Risk assessment summary for the bald eagle

	Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0.35	1.07E-05	1.07E-05	1.07E-05	1.07E-05
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Onsite Food		1.07E-05	1.07E-05	1.07E-05	1.07E-05
	Total Onsite Dose		1.07E-05	1.07E-05	1.07E-05	1.07E-05
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	0	0	0	0	0
	Small animals	0.35	0	0	0	0
	Earthworms	0	0	0	0	0
	Ground Insects	0	0	0	0	0
	Flying Insects	0	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		8.26E-10	1.44E-09	1.28E-09	8.38E-10
	Aquatic plants	0	0	0	0	0
	Aquatic inverts	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0.65	0.002 (99%ofTotalDose)	0.009 (100%ofTotalDose)	0.008 (100%ofTotalDose)	0.003 (100%ofTotalDose)
	Total Aquatic Onsite Food		2.11E-03	9.16E-03	8.24E-03	2.60E-03
	Total Aquatic Onsite Dose		2.11E-03	9.16E-03	8.24E-03	2.60E-03
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0	0	0	0	0
	Aquatic inverts 1	0	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0.65	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			2.12E-03	9.17E-03	8.25E-03	2.61E-03

Table C12 Risk assessment summary for the common merganser

Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)					
Soil		0	0	0	0
Shrubs/Trees	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0
Small animals	0	0	0	0	0
Earthworms	0	0	0	0	0
Ground Insects	0	0	0	0	0
Flying Insects	0	0	0	0	0
Total Onsite Food		0	0	0	0
Total Onsite Dose		0	0	0	0
Offsite Dose (mg/kg wet/day)					
Soil		0	0	0	0
Shrubs/Trees	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0
Small animals	0	0	0	0	0
Earthworms	0	0	0	0	0
Ground Insects	0	0	0	0	0
Flying Insects	0	0	0	0	0
Total Offsite Food		0	0	0	0
Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)					
Sediment		1.13E-06	1.37E-05	9.75E-06	1.17E-06
Water		1.03E-09	1.79E-09	1.60E-09	1.05E-09
Aquatic plants	0.02	8.64E-06	8.84E-06	8.58E-06	8.33E-06
Aquatic inverts	0.08	4.33E-05	2.98E-04	2.46E-04	4.28E-05
Amphibians	0	0	0	0	0
Fish (< 120 mm)	0.90	0.004 (99%ofTotalDose)	0.019 (98%ofTotalDose)	0.017 (98%ofTotalDose)	0.005 (99%ofTotalDose)
Fish (< 300 mm)	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Onsite Food		4.35E-03	0.020	0.017	5.41E-03
Total Aquatic Onsite Dose		4.35E-03	0.020	0.017	5.41E-03
Aquatic Items Offsite (mg/kg wet/day)					
Sediment		0	0	0	0
Water		0	0	0	0
Aquatic plants	0.02	0	0	0	0
Aquatic inverts 1	0.08	0	0	0	0
Amphibians	0	0	0	0	0
Fish (< 120 mm)	0.90	0	0	0	0
Fish (< 300 mm)	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0
Total Aquatic Offsite Food		0	0	0	0
Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)		4.35E-03	0.020	0.017	5.41E-03

Table C13 Risk assessment summary for the belted kingfisher

	Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term
Onsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	1.00E-2	9.73E-06	9.73E-06	9.73E-06	9.73E-06
	Small animals	1.00E-2	1.29E-06	1.29E-06	1.29E-06	1.29E-06
	Earthworms	5.00E-3	7.95E-07	7.95E-07	7.95E-07	7.95E-07
	Ground Insects	5.00E-3	1.74E-06	1.74E-06	1.74E-06	1.74E-06
	Flying Insects	0.02	1.54E-05	7.14E-05	6.01E-05	1.74E-05
	Total Onsite Food		2.89E-05	8.50E-05	7.37E-05	3.09E-05
	Total Onsite Dose		2.89E-05	8.50E-05	7.37E-05	3.09E-05
Offsite Dose (mg/kg wet/day)						
	Soil		0	0	0	0
	Shrubs/Trees	0	0	0	0	0
	Grasses/Herbs	1.00E-2	0	0	0	0
	Small animals	1.00E-2	0	0	0	0
	Earthworms	5.00E-3	0	0	0	0
	Ground Insects	5.00E-3	0	0	0	0
	Flying Insects	0.02	0	0	0	0
	Total Offsite Food		0	0	0	0
	Total Offsite Dose		0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		2.29E-09	3.98E-09	3.54E-09	2.33E-09
	Aquatic plants	0	0	0	0	0
	Aquatic inverts	0.10	1.19E-04	8.18E-04	6.76E-04	1.18E-04
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0.85	0.009 (98%ofTotalDose)	0.04 (98%ofTotalDose)	0.035 (98%ofTotalDose)	0.011 (99%ofTotalDose)
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Onsite Food		9.03E-03	0.041	0.036	0.011
	Total Aquatic Onsite Dose		9.03E-03	0.041	0.036	0.011
Aquatic Items Offsite (mg/kg wet/day)						
	Sediment		0	0	0	0
	Water		0	0	0	0
	Aquatic plants	0	0	0	0	0
	Aquatic inverts 1	0.10	0	0	0	0
	Amphibians	0	0	0	0	0
	Fish (< 120 mm)	0.85	0	0	0	0
	Fish (< 300 mm)	0	0	0	0	0
	Fish (< 500 mm)	0	0	0	0	0
	Total Aquatic Offsite Food		0	0	0	0
	Total Aquatic Offsite Dose		0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)			9.06E-03	0.041	0.036	0.011

Table C14. Risk assessment summary for the western toad

Media	Dietary Preferences	MeHg - Peace - Baseline	MeHg - Site C - Peak	MeHg - Site C - Peak Average	MeHg - Site C - Long Term	MeHg - Dinosaur
Onsite Dose (mg/kg wet/day)						
Soil		4.87E-07	4.87E-07	4.87E-07	4.87E-07	4.87E-07
Shrubs/Trees	0	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0	0
Small animals	0	0	0	0	0	0
Earthworms	0.35	0 (12%ofTotalDose)	8.35E-06	8.35E-06	0 (11%ofTotalDose)	0 (16%ofTotalDose)
Ground Insects	0.35	0 (25%ofTotalDose)	1.83E-05	1.83E-05	0 (25%ofTotalDose)	0 (35%ofTotalDose)
Flying Insects	0.15	0 (24%ofTotalDose)	0 (26%ofTotalDose)	0 (26%ofTotalDose)	0 (26%ofTotalDose)	0 (21%ofTotalDose)
Total Onsite Food		4.39E-05	1.07E-04	9.43E-05	4.62E-05	3.77E-05
Total Onsite Dose		4.44E-05	1.08E-04	9.48E-05	4.67E-05	3.82E-05
Offsite Dose (mg/kg wet/day)						
Soil		0	0	0	0	0
Shrubs/Trees	0	0	0	0	0	0
Grasses/Herbs	0	0	0	0	0	0
Small animals	0	0	0	0	0	0
Earthworms	0.35	0	0	0	0	0
Ground Insects	0.35	0	0	0	0	0
Flying Insects	0.15	0	0	0	0	0
Total Offsite Food		0	0	0	0	0
Total Offsite Dose		0	0	0	0	0
Aquatic Items Onsite (mg/kg wet/day)						
Sediment		1.12E-06	1.36E-05	9.68E-06	1.16E-06	2.84E-07
Water		1.57E-09	2.73E-09	2.43E-09	1.59E-09	3.80E-09
Aquatic plants	0	0	0	0	0	0
Aquatic inverts	0.15	0 (37%ofTotalDose)	0 (60%ofTotalDose)	0 (59%ofTotalDose)	0 (36%ofTotalDose)	0 (27%ofTotalDose)
Amphibians	0	0	0	0	0	0
Fish (< 120 mm)	0	0	0	0	0	0
Fish (< 300 mm)	0	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0	0
Total Aquatic Onsite Food		2.68E-05	1.84E-04	1.52E-04	2.65E-05	1.44E-05
Total Aquatic Onsite Dose		2.79E-05	1.98E-04	1.62E-04	2.76E-05	1.47E-05
Aquatic Items Offsite (mg/kg wet/day)						
Sediment		0	0	0	0	0
Water		0	0	0	0	0
Aquatic plants	0	0	0	0	0	0
Aquatic inverts 1	0.15	0	0	0	0	0
Amphibians	0	0	0	0	0	0
Fish (< 120 mm)	0	0	0	0	0	0
Fish (< 300 mm)	0	0	0	0	0	0
Fish (< 500 mm)	0	0	0	0	0	0
Total Aquatic Offsite Food		0	0	0	0	0
Total Aquatic Offsite Dose		0	0	0	0	0
Total Dose: Onsite + Offsite + Aquatic Onsite + Aquatic Offsite (mg/kg/day)		7.23E-05	3.05E-04	2.57E-04	7.43E-05	5.29E-05

APPENDIX D – RESMERC Data

Predictions of Hg Concentrations Relevant to Wildlife for the Proposed Site C Reservoir

Technical Memorandum

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April, 2013

1 Introduction

This Technical Memorandum provides predictions of total mercury (Hg) and methylmercury (MeHg) concentrations relevant to wildlife exposure for the proposed Site C reservoir in British Columbia. The information is provided in response to requests from Azimuth Consulting Group to support the Wildlife Risk Assessment (WRA) for Site C.

These estimates are supplemental to previous predictions of total Hg and MeHg concentrations in water, sediments, and an aquatic food web (plankton, benthos and fish) described by Reed Harris Environmental (2013; Mercury Technical Synthesis Report, Volume 2, Appendix J, RESMERC, Part 3). Given that RESMERC simulations were originally undertaken to support a Human Health Risk Assessment (Azimuth 2013a, Mercury Technical Synthesis Report,Volume 2, Appendix J, Part 2) the assessment endpoints were different than for the WRA. Aquatic invertebrates and fish species and sizes targeted by wildlife can be different than those presented by Azimuth (2013b; Environmental Impact Statement, Section 11.9, Methylmercury). Thus, RESMERC was also used to predict MeHg concentrations in aquatic invertebrates and fish species and sizes appropriate for the receptors of concern in the WRA including birds (merganser, belted kingfisher, eagle), mammals (otter, mink, moose) and amphibians (western toad).

Results presented previously for RESMERC simulations and those presented here are based on the same model simulations. In all cases, the predictions were made using a mechanistic model of mercury cycling and bioaccumulation, called RESMERC. A description of the RESMERC model and details of the simulations carried out for the proposed Site C Reservoir are provided by Reed Harris Environmental Ltd (2013; Mercury Technical Synthesis Report, Volume 2, Appendix J, RESMERC, Part 3).

2 Approach

The overall approach used to apply RESMERC to the proposed Site C reservoir was as follows:

1. The model calibration was updated by applying it to two full scale reservoirs created in the 1970s with long-term fish Hg datasets: Robert Bourassa Reservoir, Quebec, and Notigi Reservoir in Manitoba.
2. The updated model was then applied to pre-flood conditions in the Peace River in the vicinity of the proposed reservoir using data from baseline studies for the Site C Project.
3. RESMERC was used to simulate post-flood conditions in the Site C Reservoir and predict the magnitude and duration of changes to total Hg and MeHg concentrations in water, sediments and the food web, including key fish species in the reservoir.

Pre-flood simulations for the Peace River used available data for existing site conditions and observed concentrations of total Hg and MeHg in water, sediments and aquatic biota. Model input data were derived from field investigations in the Peace River and Dinosaur Reservoir specifically to address site-specific data requirements of the model. Full documentation of data is available in Azimuth (2011) and Azimuth (2013c; Mercury Technical Synthesis Report, Volume 2, Appendix J, Part 1.

The Site C reservoir water column was predicted to stratify vertically in the summer, but only in the downstream end (EBA Engineering 2013; Environmental Impact Statement, Section 11.7 Thermal and Ice). Because stratification can affect Hg cycling, the reservoir was divided into two reaches. The upper reach included the upstream 25 km of the reservoir, while the downstream reach included the remaining 58 km. Simulations were carried out for a post-inundation period of 50 years, long enough for predicted fish Hg concentrations to reach peak values and then decline to background levels. Concentrations estimated with the pre-flood simulation were used as the starting values for post-flood scenarios. This approach ensured that increases in MeHg concentrations predicted during the post-flood period were due to flooding rather than changes that could occur post-flood even if flooding did not occur (if the pre-flood system had not reached steady state at the time of flooding). Fish were assumed to move freely between the two modeled reaches of the Site C reservoir, and MeHg concentrations were estimated using area weighted averages of predictions for the two reaches.

Predicted Site C Reservoir simulations did not consider the potential effects of reservoir clearing or other construction phase activities, and only represented the operating phase of the Project. It was assumed that the effects of the filling period were negligible in terms of affecting peak fish mercury concentrations (expected years later), and the reservoir was treated as being at full capacity when simulations started.

As requested by Azimuth Consulting Group, monthly model outputs were averaged for the following time intervals relevant to wildlife exposure estimates: maximum annual average (“peak annual”), average for post-flood years 5 through 12, and long term averages (years 30-40). These averages were developed for the following Hg forms and compartments:

- MeHg and total Hg concentrations in each water column and sediment compartment.
- MeHg in benthic invertebrates whose MeHg exposure is linked primarily to sediments (benthic in-fauna; *e.g*., chironomids, bivalves) for each sediment compartment.
- MeHg in benthic invertebrates whose MeHg exposure is linked primarily to the water column (epibenthos; *e.g.*, mayflies, caddisflies) for each water column compartment.
- MeHg in bull trout and rainbow trout – for each age classes 0^+ to 2^+.
- MeHg in longnose sucker – for each age classes 0^+ to 5^+.
- MeHg in redside shiner – for each age classes 0^+ to 6^+.

The age classes correspond to fish whose length was predicted to be up to a maximum length of 300 mm, the largest fish size targeted by wildlife. Biomasses predicted by RESMERC were also averaged for each fish species age class over the relevant time periods, to provide an estimate of relative prey availability. Total biomasses for each fish species were inputs in RESMERC and were not explicitly modelled. The number of fish in a population at a given age was modeled using a simple exponential decay function. The biomass for a particular age class and time was obtained by multiplying of the number of fish in the age class by the weight of a single fish. Fish weights were estimated by calibrating growth rates to pre-flood observations for the study area with the exception of the redside shiner for which no growth data were available. The growth calibration for redside shiner was based on data from Scott and Crossman (1973). Simulated lengths for each fish species age class were also reported.

Ratios of post-flood to pre-flood Hg concentrations (“multipliers”) were computed based on the results of pre-flood simulations. Pre-flood values were computed as the average of RESMERC outputs for the final year of the pre-flood simulation. This was done because: 1) there were insufficient field data for existing mercury levels to assign initial conditions for many of the concentrations requested, and 2) using model results for both pre- and post-flood conditions was considered a better indicator of predicted relative increases, rather than ratios involving a combination of modeled and observed values.

3 Results

Predicted wildlife-relevant MeHg concentrations in the water column, sediments and lower food web benthic in-fauna and epibenthos are given in **Table 1**. Relevant surface areas are also included. The greatest relative increase was predicted for flooded epilimnetic wetland sediments and benthos associated with those flooded wetlands. Modest relative increases in methylmercury were predicted for the water column compartments in both reaches.

Predicted wildlife-relevant concentrations for total Hg in the water column for the two modeled reservoir reaches are provided in **Table 2**.

Predicted fish MeHg concentrations by age class for bull trout, rainbow trout, longnose sucker and redside shiner are given in **Table 3**. The range of lengths for each age class and the biomass fraction for the age classes are also included in **Table 3**. These fractions were the portions of total biomass for a given species represented by the age class. The concentrations presented in **Table 3** were area-weighted averages for the upstream and downstream reaches (the predicted concentrations in the two reaches were slightly different).

The total biomasses and biomass densities for each fish species used in RESMERC simulations of the Site C Reservoir are given in **Table 4**. Values reported represent the reservoir-wide average annual biomasses, derived from monthly model outputs for the combined upstream and downstream reaches.

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Table 1. Predicted MeHg concentrations in abiotic compartments and lower food web.

Compartment		Area (km^2)	RESMERC predicted pre-flood MeHg concentration	Concentration units	Multipliers (with respect to pre-flood)			Predicted MeHg concentration		
					Peak annual	Year 5-12	Long term	Peak annual	Year 5-12	Long term
Water Column										
Upstream reach	Epilimnion	17.6	0.02	ng/L unfiltered	1.1	1.1	1.0	0.02	0.02	0.02
Downstream reach	Epilimnion	75.7	0.02	ng/L unfiltered	1.9	1.7	1.0	0.04	0.03	0.02
	Hypolimnion	75.7	0.02	ng/L unfiltered	2.8	2.4	1.1	0.06	0.05	0.02
Sediments										
Upstream reach	Original river bed	9.62	1	ng/g dry	1.3	1.1	1.2	1	1	1
	Flooded upland	7.88	1	ng/g dry	13.7	10.1	0.8	15	11	1
	Flooded wetland	0.13	1	ng/g dry	16.0	10.9	2.3	18	12	3
Downstream reach	Original river bed	29.7	1	ng/g dry	1.9	1.2	1.7	2	1	2
	Hypolimnetic flooded upland	32.5	1	ng/g dry	14.1	10.9	1.0	16	12	1
	Hypolimnetic flooded wetland	0.53	1	ng/g dry	16.6	12.1	2.5	19	14	3
	Epilimnetic flooded upland	12.8	1	ng/g dry	19.1	13.3	1.0	22	15	1
	Epilimnetic flooded wetland	0.21	1	ng/g dry	22.5	14.8	3.1	25	17	3
Benthic In-Fauna										
Upstream reach	Original river bed	9.62	5	ng/g wet	1.3	1.1	1.3	6	5	6
	Flooded upland	7.88	5	ng/g wet	7.6	6.5	0.7	36	30	3
	Flooded wetland	0.13	5	ng/g wet	8.6	7.0	2.1	41	33	10
Downstream reach	Original river bed	29.7	5	ng/g wet	1.8	1.2	1.6	9	5	8
	Hypolimnetic flooded upland	32.5	5	ng/g wet	8.1	7.1	0.9	38	34	4
	Hypolimnetic flooded wetland	0.53	5	ng/g wet	9.4	8.0	2.3	44	37	11
	Epilimnetic flooded upland	12.8	5	ng/g wet	10.5	8.6	0.9	49	40	4
	Epilimnetic flooded wetland	0.21	5	ng/g wet	12.1	9.6	2.8	57	45	13
Epibenthos										
Upstream reach	Epilimnion	17.6	4	ng/g wet	1.1	1.1	1.0	5	5	4
Downstream reach	Epilimnion	75.7	4	ng/g wet	1.9	1.7	1.0	8	7	5

Table 2. Predicted dissolved total Hg concentrations in water

Compartment		Area (km^2)	Predicted pre-flood total Hg concentrations (ng/L dissolved)	Predicted post-flood total Hg concentrations					
				Multiplier			Concentration (ng/L dissolved)		
				Peak annual	Year 5-12	Long term	Peak annual	Year 5-12	Long term
Upstream reach	Epilimnion	17.6	0.63	1.02	1.00	0.99	0.65	0.63	0.62
Downstream reach	Epilimnion	75.7	0.63	1.05	0.99	0.96	0.66	0.62	0.60
	Hypolimnion	75.7	0.63	1.14	1.05	0.97	0.71	0.66	0.61

Table 3. Predicted MeHg concentrations in fish

Species	Age class	Minimum length (mm)	Maximum length (mm)	Percent of total species biomass in age class	Predicted pre-flood concentration (mg/kg wet muscle)	Predicted post-flood concentrations					
						Multipliers			Concentration (mg/kg wet muscle)		
						Peak Annual	Year 5-12	Long term	Peak Annual	Year 5-12	Long term
Bull Trout	0+	15	116	<1	0.03	4.1	3.6	1.1	0.12	0.10	0.03
	1+	103	246	<1	0.04	3.6	3.1	0.9	0.14	0.13	0.04
	2+	204	368	1	0.06	4.4	4.0	1.3	0.26	0.23	0.07
Rainbow Trout	0+	17	163	1	0.02	4.6	3.9	1.1	0.08	0.07	0.02
	1+	139	294	8	0.03	4.4	3.8	1.1	0.12	0.10	0.03
	2+	247	402	16	0.04	4.3	3.8	1.1	0.15	0.13	0.04
Longnose Sucker	0+	14	100	18	0.01	8.8	7.6	1.9	0.06	0.05	0.01
	1+	86	175	15	0.01	8.9	7.8	2.0	0.08	0.07	0.02
	2+	148	238	12	0.01	8.9	7.9	2.0	0.10	0.09	0.02
	3+	201	286	10	0.02	7.8	6.9	1.7	0.12	0.11	0.03
	4+	243	325	8	0.02	6.6	6.0	1.5	0.14	0.13	0.03
	5+	278	357	7	0.03	6.2	5.6	1.4	0.16	0.15	0.04
Redside Shiner	0+	16	54	2	0.02	3.4	3.0	1.1	0.08	0.07	0.03
	1+	50	86	8	0.03	3.5	3.1	1.1	0.10	0.09	0.03
	2+	76	111	15	0.04	3.5	3.1	1.1	0.12	0.11	0.04
	3+	97	131	20	0.04	3.3	3.0	1.1	0.13	0.12	0.04
	4+	115	148	21	0.04	3.2	2.9	1.1	0.14	0.12	0.05
	5+	131	162	19	0.05	3.1	2.9	1.1	0.15	0.13	0.05
	6+	144	173	16	0.05	3.2	2.9	1.1	0.16	0.15	0.06

Table 4. Fish species biomass specified in the RESMERC simulation.

Fish species	**Biomass (tonnes)**	**Biomass (kg/ha)**
Bull Trout	11	1.2
Rainbow Trout	11	1.2
Longnose Sucker	164	17.6
Redside Shiner	108	11.6

APPENDIX E – Dose-Response Assessment for Methylmercury and Birds

Appendix E: Dose-Response Assessment for Methylmercury and Birds

This appendix reviews data that relate potential effects in birds to methylmercury exposure. The analysis is tailored to the context of estimated exposure for Site C (the highest estimated exposure occurs for the belted kingfisher in the Site C - Peak scenario). Three different types of data are considered:

1. Laboratory-based studies relating methylmercury dose to effects on survival, reproduction and growth.
2. Field studies relating methylmercury dose to adverse effects on survival, reproduction and growth.
3. Data relating dietary concentrations of methylmercury to adverse effects on loons (based on a review paper by Depew et al. 2012).

Laboratory Studies of Methylmercury Dose-Response

We compiled laboratory studies relating methylmercury dose to response for survival, reproduction and growth endpoints. Among these, we excluded any studies where:

- The administrative route was injection rather than oral ingestion;
- The form of mercury was inorganic mercury rather than methylmercury;
- There were confounding contaminants noted that could have caused the observed responses;
- There was no appropriate laboratory control (e.g., control animals were subject to non-negligible dose, or were dosed in a different way than treatment animals); or
- Sample size was small (n=5 or less) in a treatment group or in the control.

Statistical significance was not used as a criterion for excluding data points.

In cases where dose was not reported, we estimated dose based on dietary concentration and food ingestion rate (where the latter is based on allometric equations using body weight for all birds or for passerines; Nagy 1987).

The final data set was based on 26 different studies, covering 13 different species and several endpoints.

We evaluated the data using several plots. In all cases, plotted values were normalized positive responses (i.e., treatment response divided by control response), so that data could be compared across studies. On all plots a dashed vertical line was used to indicate the estimated dose for belted kingfisher under worst-case model predictions (i.e., Site C - Peak scenario) – that dose was 0.041 mg/kg methylmercury/day). A large proportion of the reproductive data are considered partial or redundant endpoints. Many studies measure multiple endpoints that integrate other endpoints. For example, egg fertility is a partial contributor to total reproductive output measured as the number of offspring. We include these partial or redundant data points in some plots, but not others as appropriate.

We can expect differences in dose-response relationships among studies due to differences in species, lifestage, feed type, chemical form, dose duration, dose reporting, or other factors. Most plots were therefore organized by study.

Horizontal lines on all plots are provided at a value of 80% positive response relative to control, which is equivalent to a 20% effect size relative to control. This is a common benchmark used in ecological risk assessments (SAB 2008) and is useful as an initial guide to interpretation. Thus, any data in the lower left portion of each plot (i.e., the grey solid shaded area indicating positive response < 80% at doses below that estimated for belted kingfisher) may be of potential concern.

The following plots are provided:

- **Figure E1**: Bird survival by study, with data points differentiated by species and duration of exposure. These data represent a mix of sexes (male, female, or both) and life stages (juvenile or adult).
- **Figure E2:** Bird survival pooled across all studies, with data points differentiated by species and life stage.

- **Figure E3**: Bird growth by study (final body weight, scaled to control start weight for adults), differentiated by species and duration of exposure.
- **Figure E4**: Bird growth pooled across all studies, with data points differentiated by species and life stage.
- **Figure E5**: Offspring production by study[1], measured as the number of offspring per female or breeding pair (e.g., number successfully hatched, fledged, or alive after x weeks). Offspring production is the best measure of total reproductive output. Data points differentiated by species and duration of exposure.
- **Figure E6:** Total reproductive output pooled across all studies[2]. Data points differentiated by species.
- **Figure E7:** Egg production and offspring survival for studies that did not report offspring production. Data points differentiated by species and specific endpoint.
- **Figure E8:** Reproductive data by endpoint shows plots by specific reproductive endpoint across studies. Data points differentiated by species and duration of exposure.
- **Figure E9**: Same data as **Figure E6**, but with the estimated dose plotted for estimated Peace – Baseline conditions and estimated Site C - Peak. An empirically fit dose-response curve is used to provide rough indication of the expected change in reproductive output with the increase in dose from Peace - Baseline to Site C - Peak.

Looking across the plots, there appears to be very little probability of any effects on survival or growth. For reproduction, however, there are two data points that show positive response below 80% at doses equal to or less than the belted kingfisher dose. These two data points come from a study by Frederick and Jayasena (2011) on the white ibis. Their results indicated a reduction in fledgling production to under 70% (relative to control) at less than the 0.041 mg/kg-day, the

[1] Figures 5 and 6 omit a single data point (Heinz et al. 2010) for “Number of 6 day old ducklings produced” because it distorted the figures. The response was 127% at a dose of 0.037 (apparent hormesis in this mallard study, but dosing duration was only 26 days and the authors were surprised by the result). The specific endpoints reported for this study are included in subsequent figures.

[2] See previous footnote

Site C Peak estimated does for the belted kingfisher (see **Figures E5, E6, E8**). However, that same study had another treatment group at a dose level in between that of the two data points in question, and that treatment group actually performed better than control. When examining the offspring production data together (**Figure E6**), it is clear that there is a lot of uncertainty, in part because there are only three data points at doses below that estimated for the belted kingfisher. Overall, however, the white ibis data do not seem particularly out of place. The kestrel data (Albers et al. 2007) seem to show a consistent dose-response relationship, but that study did not include treatment groups with doses as low as that estimated for the belted kingfisher. We have not fit a dose-response model to the data set in **Figure E5**, given the paucity of data relative to the number of studies and species depicted. However, rough visual interpretation of the data indicates that we might expect, at the dose estimated for the belted kingfisher, reproductive output in the range of 60 to 90% of what we could expect for control groups – in other words, a 10% to 40% reduction in reproductive output relative to the control. However, the dose-response information levels off at low doses, and there is little indication that reproductive output would be much different at the predicted peak dose (Site C – Peak, 0.041 mg/kg-day; red vertical line) compared to the dose predicted for Peace - Baseline conditions (0.0091 mg/kg-day).

To evaluate this further, the Peace - Baseline and Site C - Peak doses for the belted kingfisher and other bird receptors were plotted on the data for reproductive output (**Figure E9**). In addition, we fit an approximate dose-response curve to the data to provide some indication of the likely dose-response relationship[3]. A very flexible 5-parameter model (generalized logistic function) that can be used to describe dose-response curves of the form **Y** ~ **log(Dose)** is the Richards function (Huet et al. 2004, page 3):

$$f(x,\theta) = \theta_1 + \frac{\theta_2 - \theta_1}{(1 + \exp[\theta_3 + \theta_4 x])^{\theta_5}}$$

[3] The approach is empirical, and fails to account for the underlying binomial nature of the data. Thus, no information on the number of organisms is accounted for. In addition, the nonlinear least squares fitting procedure assumes equal variances across x-values, which is inappropriate for binomial data where we expect smaller variance at the tails.

where x = log(d), q_1 is the lower asymptote, q_2 is the upper asymptote, and the other parameters describe the increasing or decreasing shape of the curve. In the current case based on normalized response data, the asymptotes are $q_1 = 0$ and $q_2 = 100$, giving:

$$f(x,\theta) = \frac{100}{(1+\exp[\theta_3 + \theta_4 x])^{\theta_5}} \; .$$

We set the shape parameter q_5 equal to 1 for simplicity, therefore only q_3 and q_4 need to be estimated, and the function would be equivalent to a logistic model if the data were binomial. Fitting of the model to data sets was completed using nonlinear least squares, based on the nls procedure in R software version 2.15.2 (Venables and Ripley 2002). Using the fitted curve, we can make a best guess at the normalized response associated with each dose, and then determine the relative change.

Results are as follows:

	Expected Normalized Response: Peace - Baseline	Expected Normalized Response: Site C-Peak	Expected Reduction in Offspring Production[4]
belted kingfisher	89.6	74.6	16.8 %
common merganser	93.6	83.3	11 %
Canada goose	99.1	99.1	0
mallard	98.3	95.7	2.6 %
bank swallow	97.4	92.6	4.1 %
spotted sandpiper	96.7	90.6	5.3 %
bald eagle	96.1	89.6	6.1 %

[4] Calculated as (base-peak)/base

These results indicate that we would expect a low magnitude (<20%) reduction in offspring production relative to Peace - Baseline conditions for the belted kingfisher and the common merganser, and negligible reduction (<10%) for the other bird receptors. Importantly, these reductions would be short-term; for the Site C – Long Term scenario the reduction in offspring production for the belted kingfisher is estimated at < 3%.

Field Studies of Methylmercury Dose-Response

Field studies were evaluated separately from laboratory studies. Although field studies are arguably more ecologically relevant than laboratory studies, it is virtually impossible to design a proper control in a field setting due to spatial heterogeneity, thus making it more difficult to attribute observed differences between treatments and controls to methylmercury. Nevertheless, taken together the field studies provide an important set of data that provides insight into potential exposure-response relationships. Available field data (that met the criteria for data selection outlined for laboratory studies above) are summarized in **Figure E10**. Most of the studies either do not show any indication of effects at the dose estimated for the belted kingfisher, or lack adequate data across a range of doses that would allow inference regarding dose-response. A key exception is the Barr (1986) study of offspring production in the loon – the data for that study, which are further supported by the data from Burgess and Meyer (2008), indicate that effects on loon reproduction are possible at the dose estimated for the belted kingfisher. However, there is considerable variability in the data that make it difficult to specify the potential magnitude of effects.

Data Relating Dietary Concentrations of Methylmercury to Effects on Loons

A recent review by Depew et al. (2012) has evaluated data relating effects on loon reproduction to dietary concentrations of methylmercury in fish. Loons, like kingfishers, are piscivorous. In addition, for a given dietary concentration, the implications of reproductive effects at population level may be more important for loons than many other birds because of low annual productivity, delayed sexual maturity, long life expectancy and suspected low adult mortality. The review is based on field studies and captive breeding studies, because laboratory studies are difficult to conduct with the common loon. The data set includes studies from the grey literature that we have not reviewed, as well as studies that did not meet our criteria for dose-based studies (e.g., studies with injection as the method of dose administration). Consequently the Depew et al. (2012) review may provide additional insight into potential exposure-response relationships for methylmercury and birds. Among the studies they used, many did not provide information on dietary concentrations, in which case blood concentrations in the loon were converted to estimate dietary item concentration using an empirical relationship applicable for fish in the size range typically consumed by loons (10 to 15cm; this size range is also relevant for belted kingfisher). There was considerable uncertainty in the blood to diet item relationship, however. For studies lacking blood data, conversions were made based on other tissue concentrations in the loon.

Depew et al. (2012) proposed screening benchmarks for the loon, based on the concentration of methylmercury in fish of the size range 10 to 15 cm. These were 0.1 mg/kg wet weight as a benchmark for the threshold for behavioural effects; 0.18 mg/kg wet weight as a benchmark threshold for significant reproductive impairment; and 0.40 mg/kg wet weight as a benchmark threshold for complete reproductive failure. All of these values are above the modeled average concentration for fish in the < 12 cm range, which was 0.09 mg/kg wet weight for the Site C - Peak (worst-case scenario). Even when larger fish up to 30 cm are included, the modeled average concentration was only 0.12 mg/kg wet weight, below the benchmarks for reproductive effects. These modeled concentrations would suggest that effects on the loon would not be expected. It is useful to compare this finding to the dose-response data compiled from laboratory studies above. If we assume that a loon has a food intake rate of 0.19 kg of food (wet weight) per kg body weight per day (FCSAP 2012), the daily dose of methylmercury for the Site C - Peak scenario would be (0.19 * 0.09) = 0.017 mg/kg-day. This assumes the entire diet is fish (aquatic insects are also part of the loon diet, but typically 10% or so – FCSAP 2012) and ignores consumption of water. A dose of 0.017 mg/kg-day is much less than the dose estimated for the belted kingfisher (0.041 mg/kg-day), which makes sense because the belted kingfisher is smaller and therefore we expect a greater food consumption rate per kg body weight. If the loon were a receptor of concern for the site, we would expect reproductive impairment (if any) to be low – lower than for the belted kingfisher based on the data set of laboratory studies for other species. This is consistent with the Depew et al (2012) recommendations for tissue concentration benchmarks.

Conclusions

We considered three separate types of information in evaluating potential risks to the belted kingfisher (and other bird receptors as appropriate):

1. Based on data for laboratory studies, we could expect low reductions in offspring production (<20%) for the belted kingfisher and common merganser for the Site C - Peak scenario relative to Peace – Baseline conditions, and negligible reductions (<10%) for other bird receptors. All effects would be negligible under the Site C – Long Term scenario. There is high uncertainty because data are limited, and there are no data specifically for the species of interest. Relative to lab controls, expected effects on the belted kingfisher at Site C would be considered low to moderate (i.e., possibly higher than a 20% reduction in offspring production), and expected effects for Peace – Baseline conditions would be considered negligible to low (i.e., around 10% for the belted kingfisher).
2. Field-based dose-response data are available for several species, but only the loon data indicate potential for effects (in the same range as estimated from lab data) at the estimated dose levels for Site C. However, the field data for the loon are highly uncertain. We put more weight on our findings from laboratory studies across numerous species than on the loon field studies because the latter are limited, and more likely to be confounded by spatial heterogeneity in habitat, environmental influences and other factors.
3. Fish tissue-based benchmarks recently put forth for the loon are higher than estimated concentrations for Site C, which suggests that effects on loons would not be expected.

In conclusion, we would expect a low reduction in offspring production for the belted kingfisher and possibly for the common merganser for the Site C - Peak scenario relative to Peace – Baseline conditions. We would expect negligible effects on other receptors. In all cases the effects would be negligible for the Site C – Long Term scenario. There is moderate to high uncertainty in this conclusion.

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Figure E1. Methylmercury dose-response data for bird survival, by study

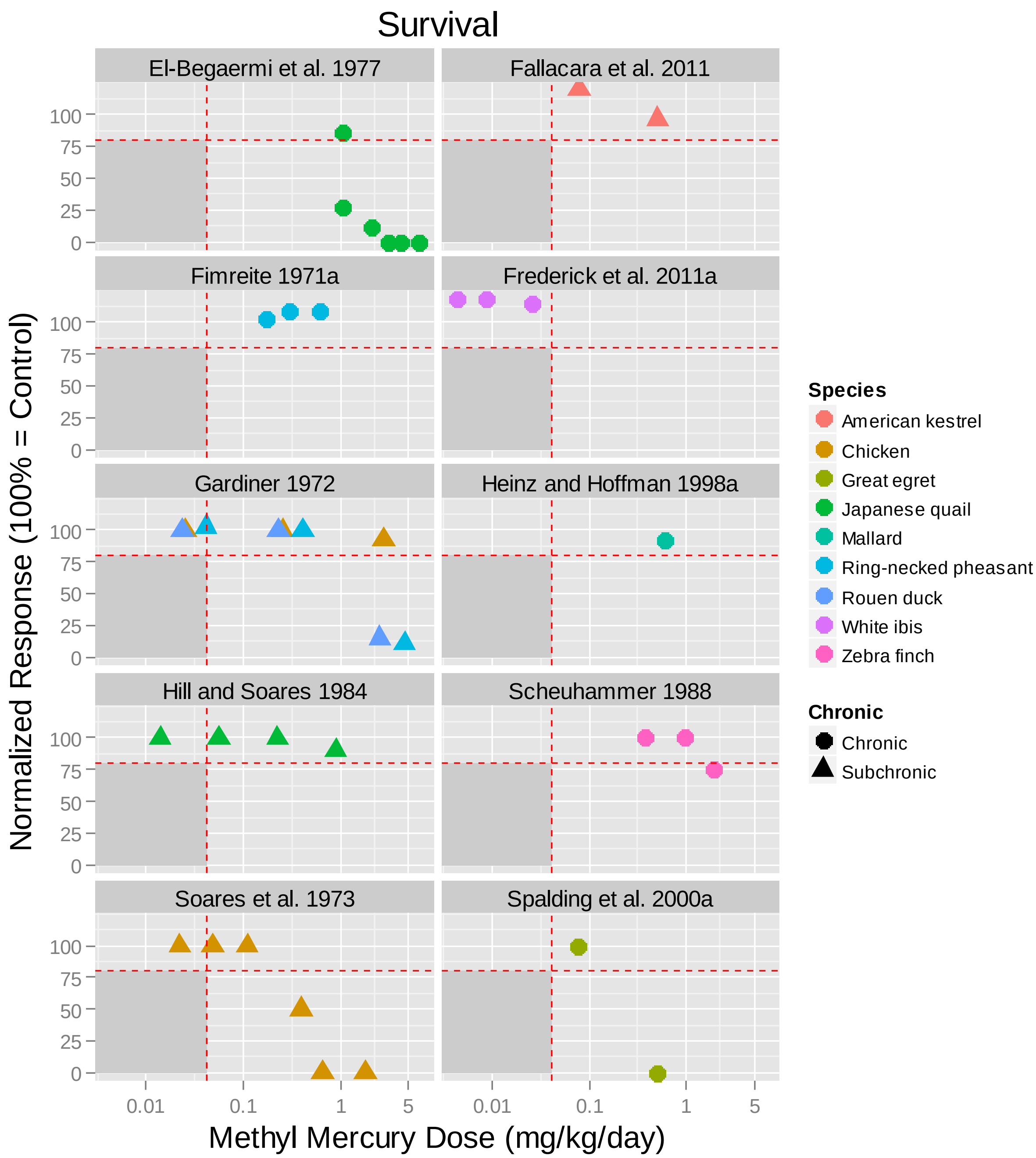


Figure E2. Methylmercury dose-response data for bird survival, pooled across studies

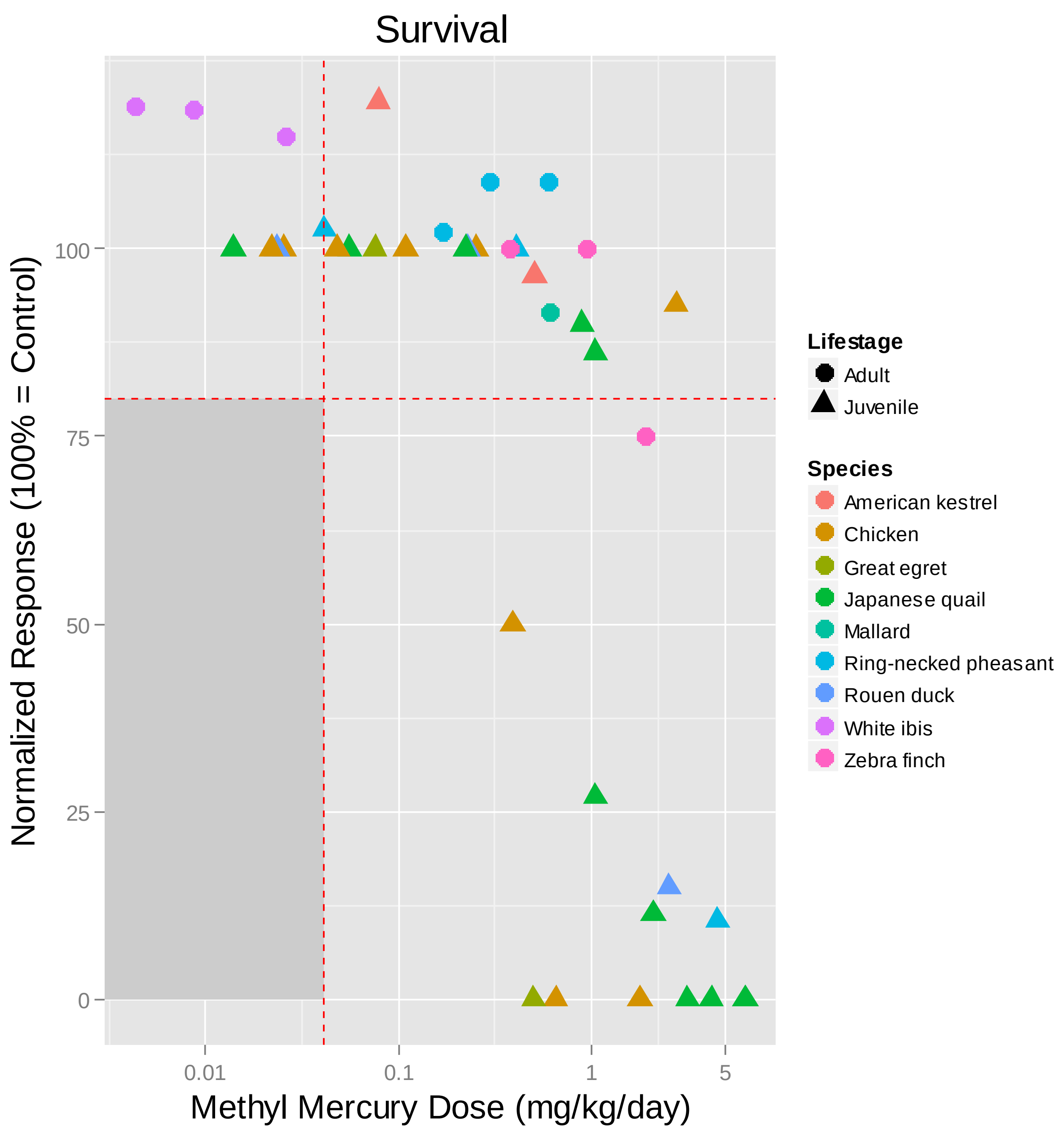


Figure E3. Methylmercury dose-response data for bird growth, by study

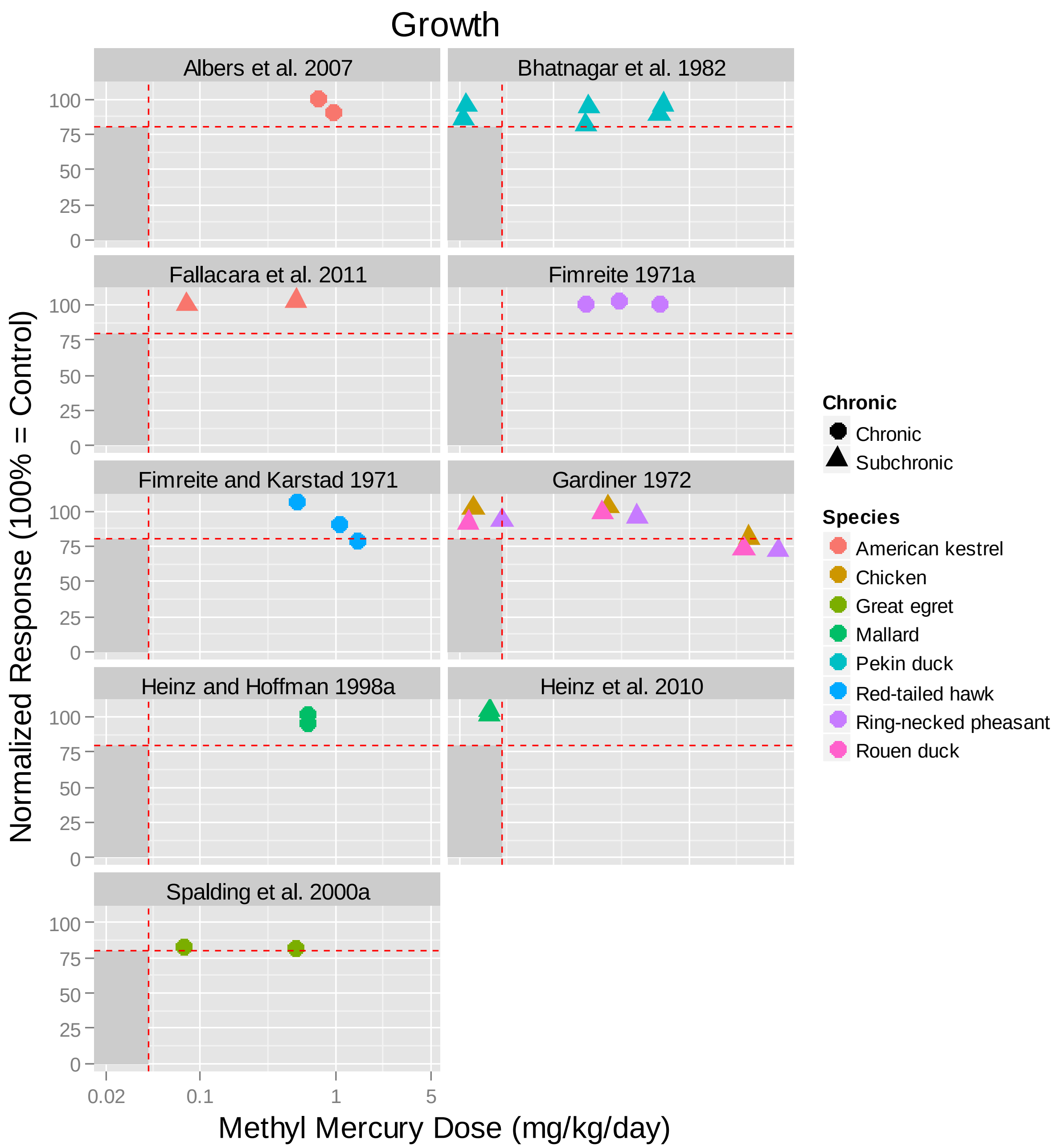


Figure E4. Methylmercury dose-response data for bird growth, pooled across studies

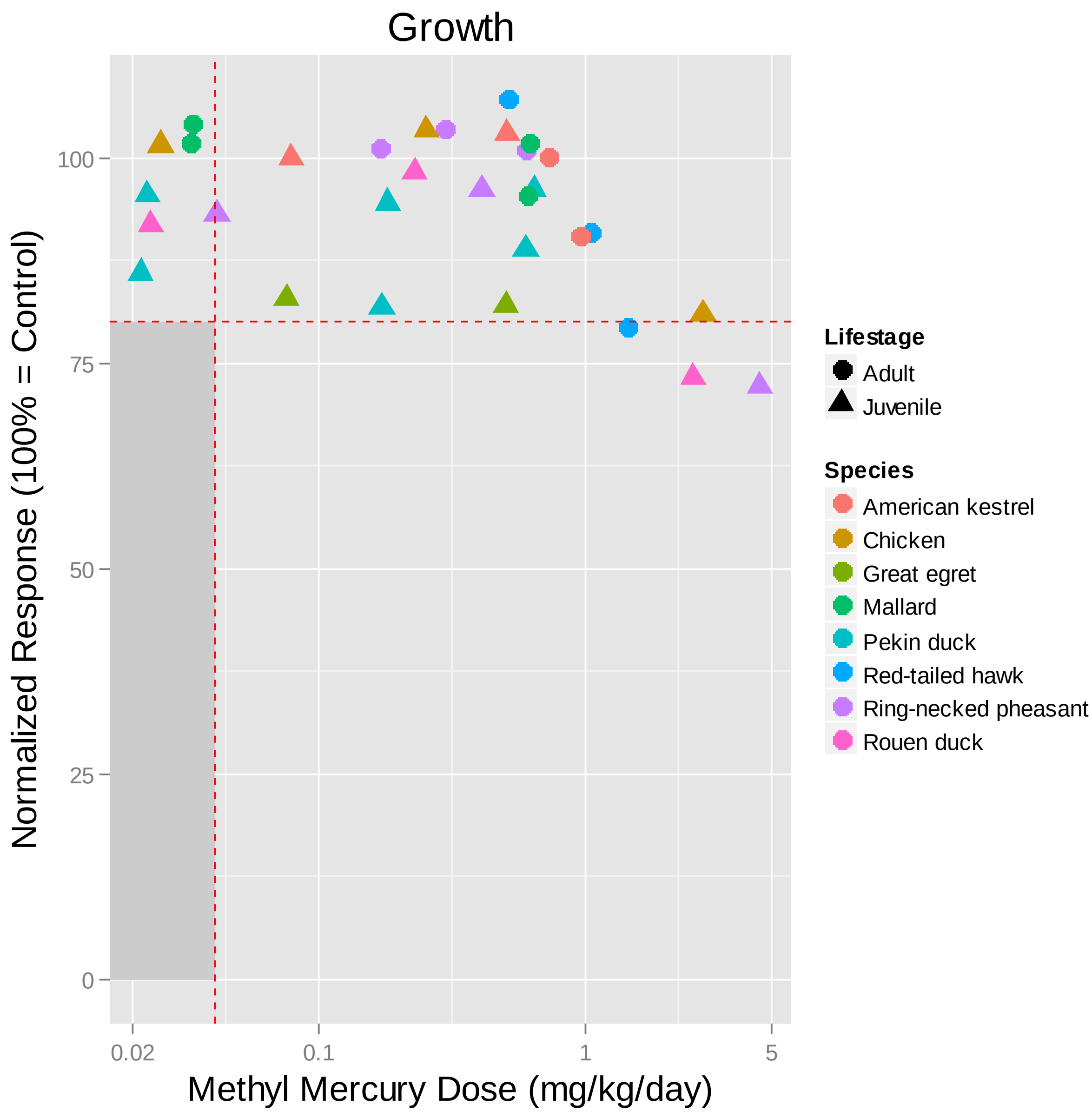


Figure E5. Methylmercury dose-response data for bird offspring production, by study

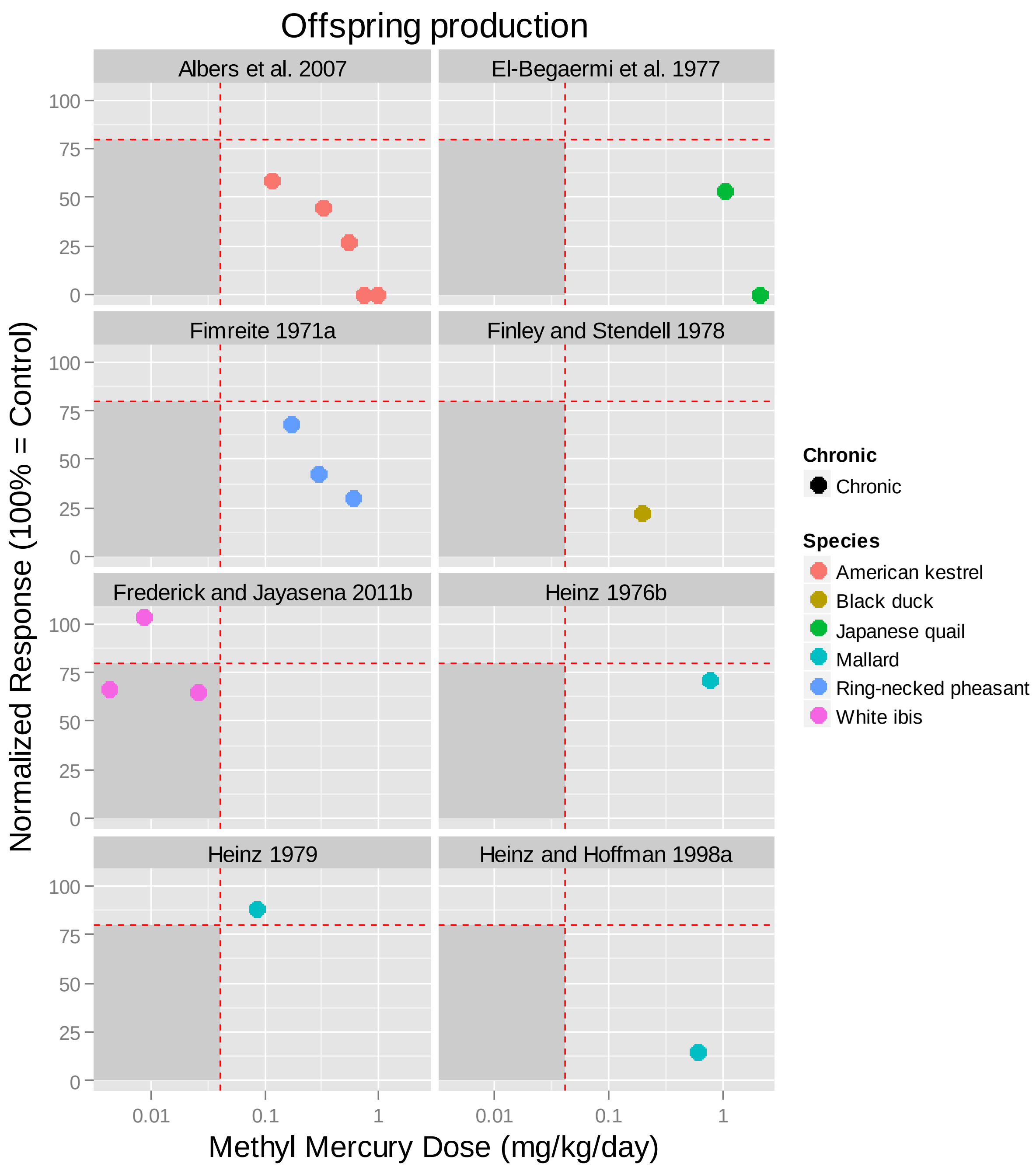


Figure E6. Methylmercury dose-response data for bird offspring production, pooled across studies

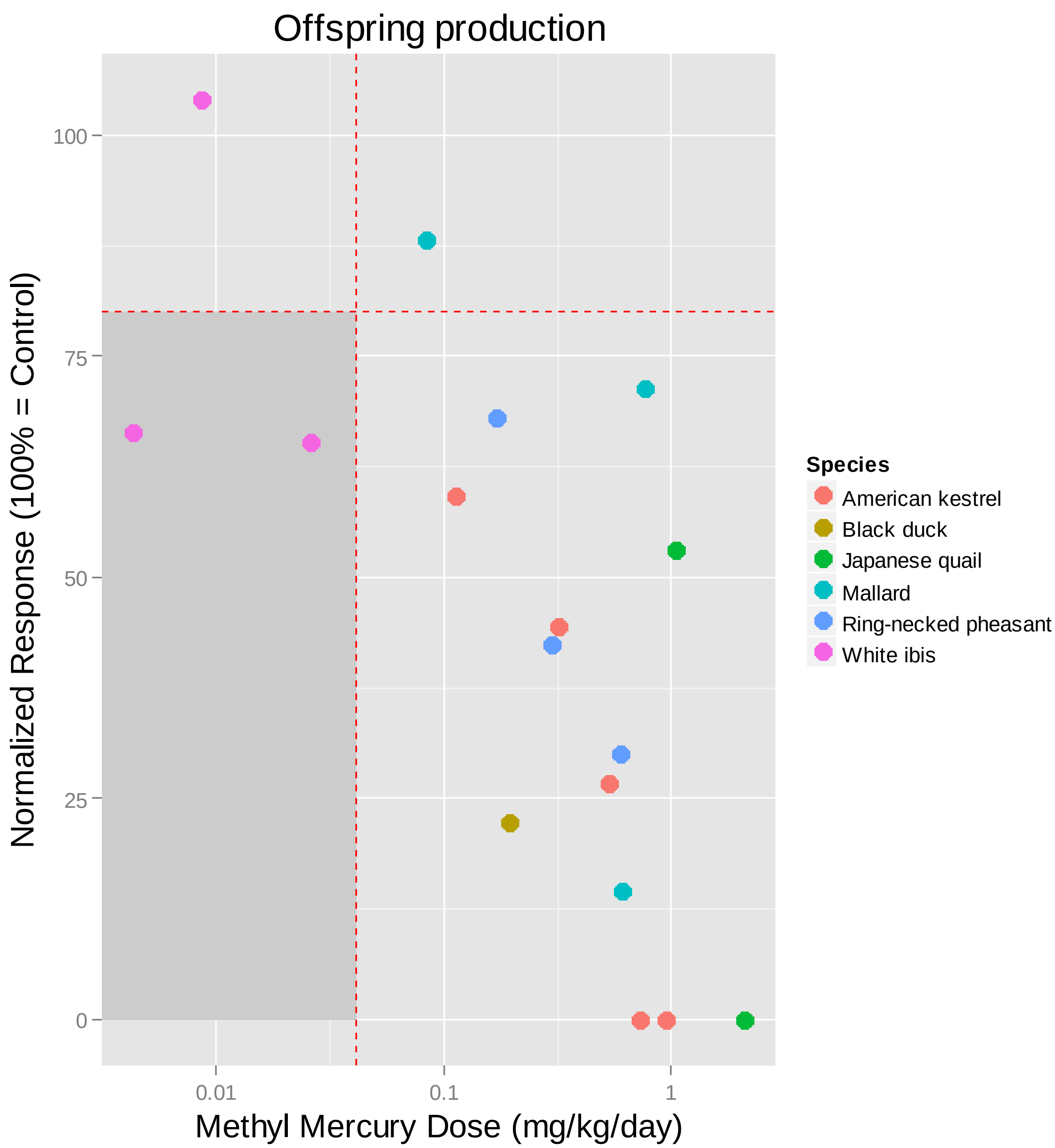


Figure E7. Methylmercury dose-response data for bird egg production and offspring survival, for studies not reporting total offspring production

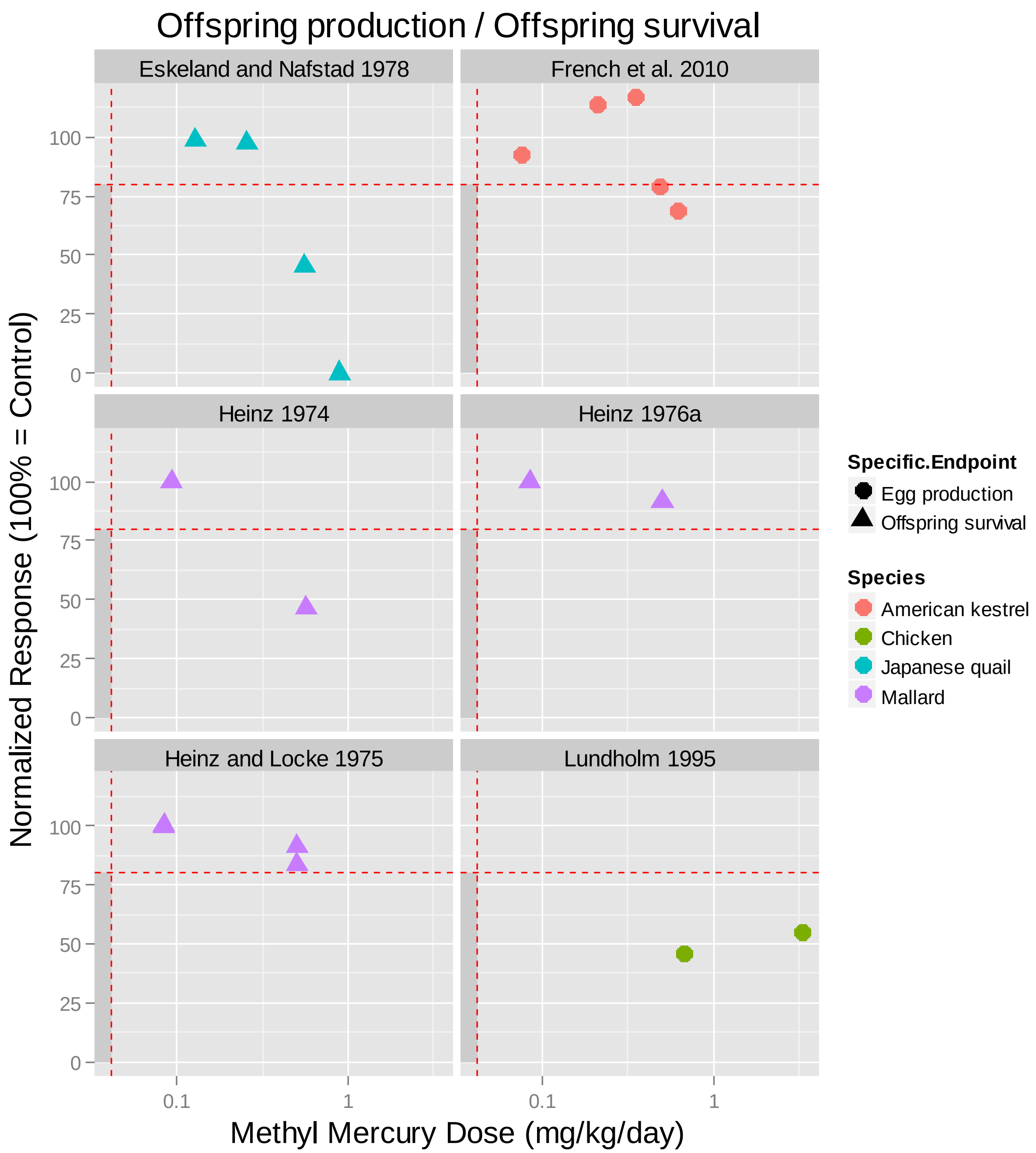


Figure E8. Complete methylmercury dose-response data set for specific bird reproductive endpoints

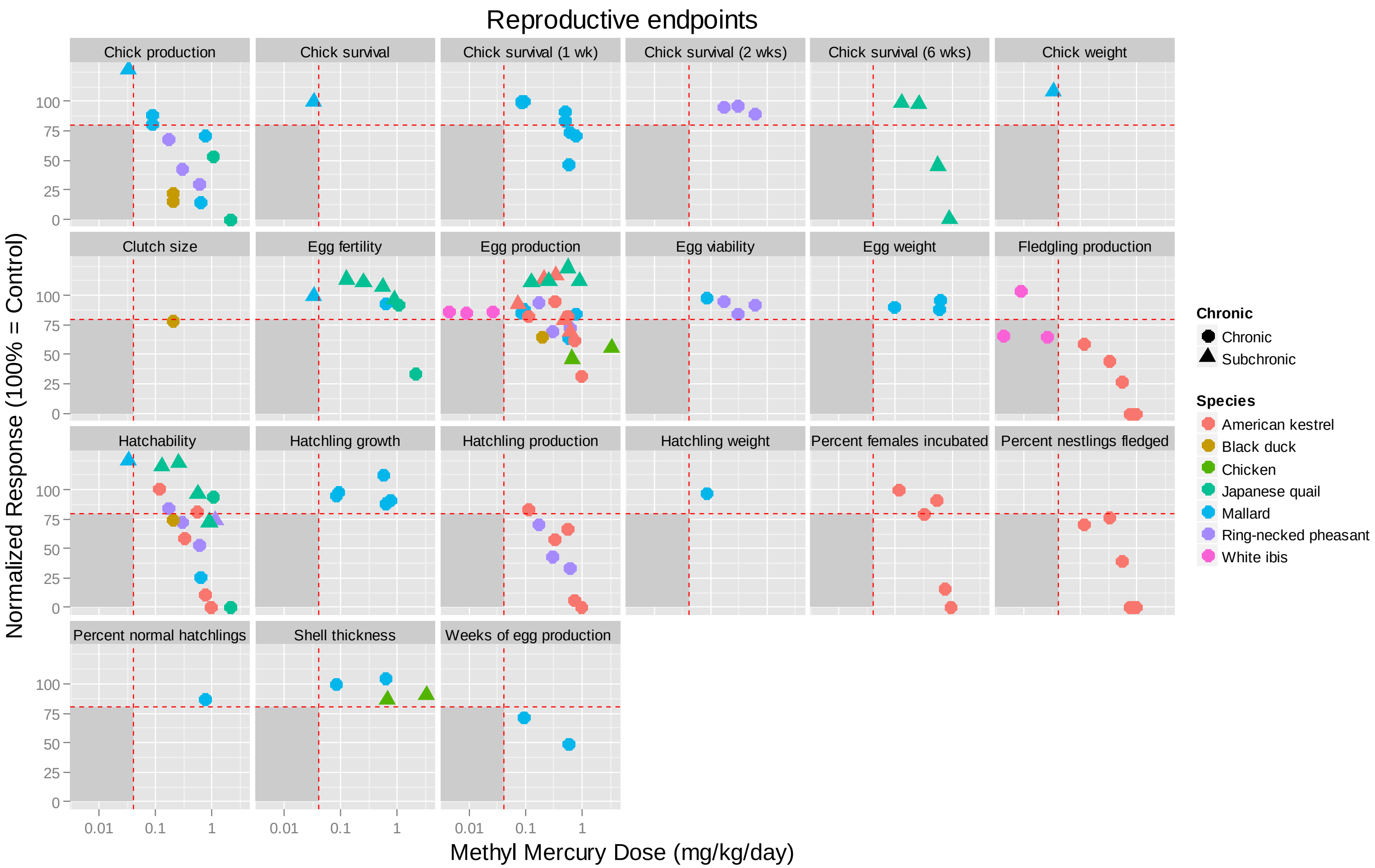


Figure E9. Comparison of dose and expected effect on bird offspring production for the Site C - Peak and Peace – Baseline scenarios. *The left vertical solid red lines are equal to background dose, while the right dashed vertical lines are equal to estimated Site C - Peak dose. For Canada goose the lines are almost identical and are therefore indistinguishable. The blue solid line is an empirically fit dose-response curve.*

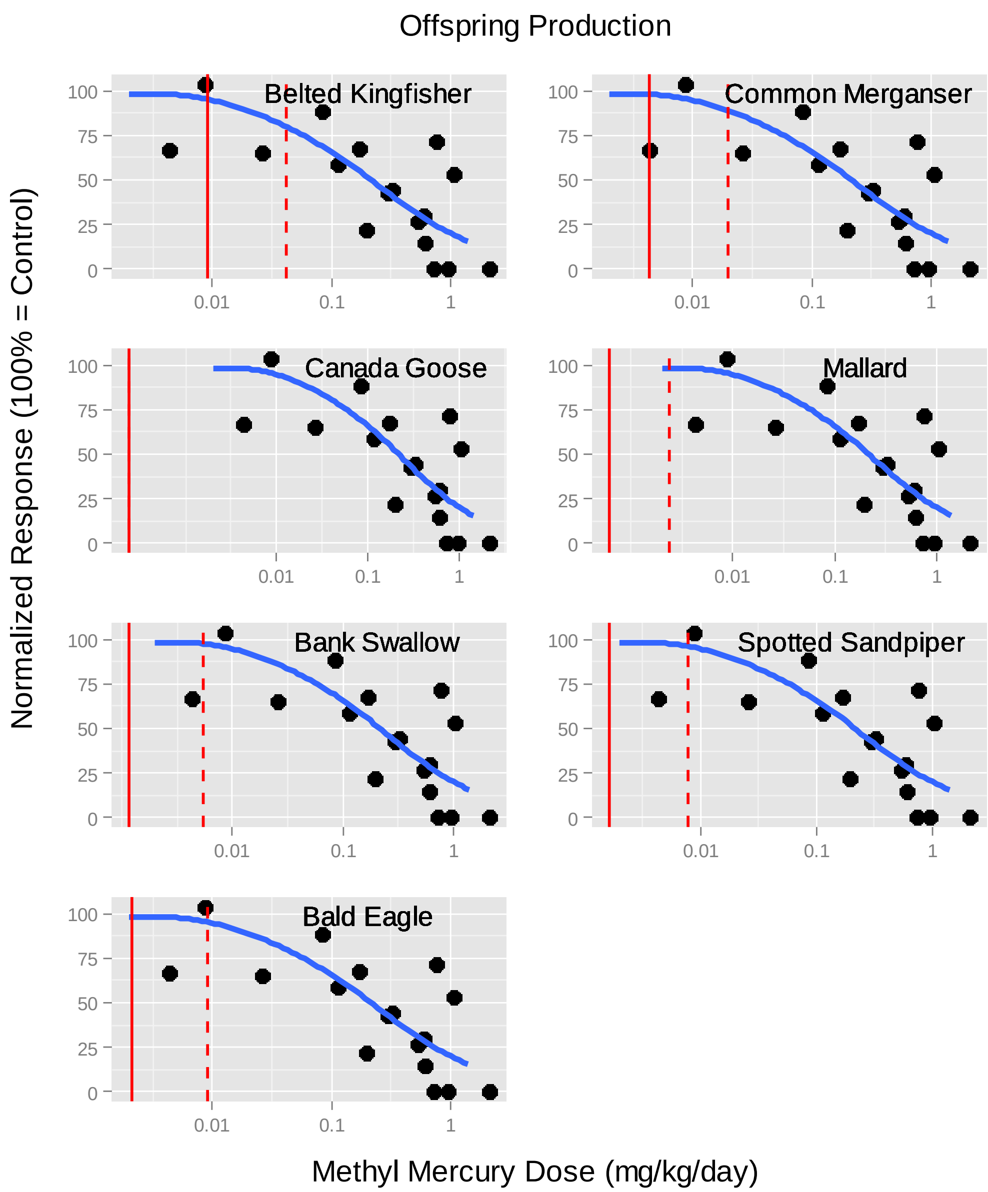
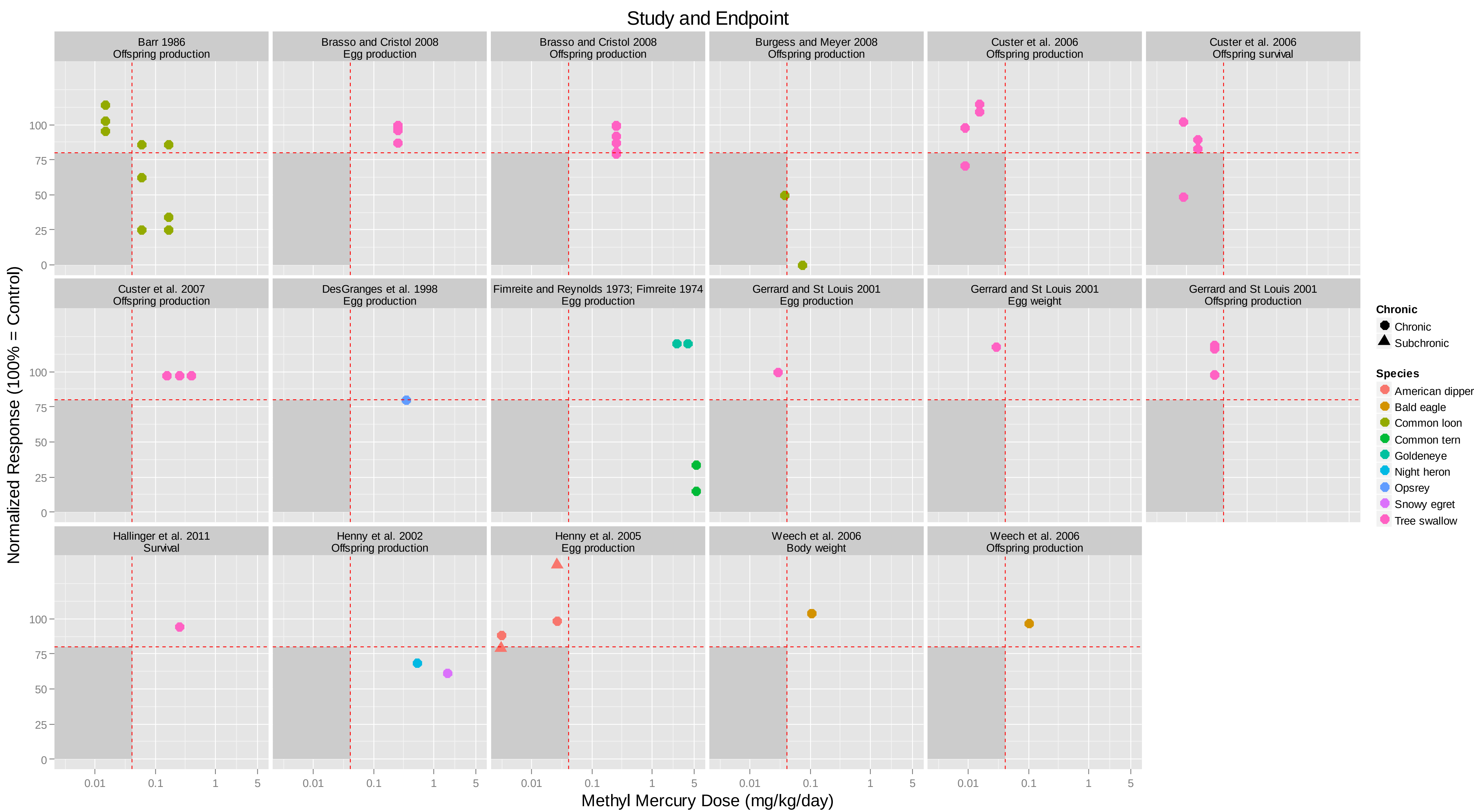


Figure E10. Methylmercury dose-data for birds from field studies



APPENDIX F – Dose-Response Assessment for Methylmercury and Mammals

Appendix F: Dose-Response Assessment for Methylmercury and Mammals

This appendix reviews data that relate potential effects in mammals to methylmercury exposure. The analysis is tailored to the context of estimated exposure for Site C (the highest estimated exposure occurs for the northern river otter in the Site C - Peak scenario). The analysis is based on data from laboratory-based studies relating methylmercury dose to effects on survival, reproduction and growth.

Methods

We compiled laboratory studies relating methylmercury dose to response for survival, reproduction and growth endpoints. Among these, we excluded any studies where:

- The administrative route was injection rather than oral ingestion;
- The form of mercury was inorganic mercury rather than methylmercury;
- There were confounding contaminants noted that could have caused the observed responses;
- There was no appropriate laboratory control (e.g., control animals were subject to non-negligible dose, or were dosed in a different way than treatment animals); or
- Sample size was small (n=5 or less) in a treatment group or in the control.

Statistical significance was not used as a criterion for excluding data points.

In cases where dose was not reported, we estimated dose based on dietary concentration and food ingestion rate (where the latter is based on allometric equations using body weight for all mammals; Nagy 1987).

The final data set was divided into two parts. The mink and otter data are most relevant, but are challenging due to small sample sizes and non-zero doses for control groups. Normally these studies would be excluded, but in this case we retained them because of their direct relevance to the northern river otter. These studies are presented in tables because studies cannot be easily compared to each other.

The rest of the data were evaluated using plots – after data filtering using the above criteria this included 14 studies covering three species and several endpoints. In all cases, plotted values were normalized positive responses (i.e., treatment response divided by control response), so that data could be compared across studies. On all plots a dashed vertical line was used to indicate the estimated dose for the northern river otter under worst-case model predictions (i.e., Site C - Peak scenario) – that dose was 0.0129 mg/kg of methylmercury/day).

We can expect differences in dose-response relationships among studies due to differences in species, developmental stage, feed type, chemical form, dose duration, dose reporting, or other factors. Most plots were therefore organized by study.

Horizontal lines on all plots are provided at a value of 80% positive response relative to control, which is equivalent to a 20% effect size relative to control. This is a common benchmark used in ecological risk assessments (SAB 2008) as a guide to interpretation. Thus, any data in the lower left portion of each plot (i.e., the grey solid shaded area indicating positive response < 80% at doses below that estimated for otter) may be of potential concern.

Results for Mink and Otter Studies

The dataset contains five mink studies (summarized in **Table F1**) and one otter study (**Table F2**). The mink studies were not plotted because several studies had controls with non-zero doses (dietary Hg concentrations in feed were analyzed). These control doses are generally higher than the Site C - Peak dose for the northern river otter (0.0129 mg/kg/day).The reproductive endpoints were reported as (paraphrased) “offspring/female to weaning (70d)” for first-generation results for Dansereau et al. 1999 and “average # kits per female at 5 wks” for Wren et al. 1987b (for the latter, the dosing pattern was unclear, but could have been up to 8 months). The mink data suggest that effects on survival or reproduction at the estimated dose for the northern river otter are unlikely. The otter study is too uncertain to be useful (because of small sample sizes), but was tabulated because the northern river otter is the species of mammal with highest estimated dose for Site C (i.e., Site C – Peak).

Results for Other Mammals

For other mammals, the following plots are provided:

- **Figure F1**: Mammal survival by study, with data points differentiated by species and duration of exposure. These data represent a mix of sexes (male, female, or both) and life stages (juvenile or adult).
- **Figure F2:** Mammal survival pooled across all studies, with data points differentiated by species and life stage.
- **Figure F3**: Mammal growth by study (final body weight, scaled to control start weight for adults), differentiated by species and duration of exposure.
- **Figure F4**: Mammal growth pooled across all studies, with data points differentiated by species and life stage.
- **Figure F5**: Offspring production by study, with data points differentiated by species and duration of exposure.

Looking across the plots, there is no indication of potential effects for any of the endpoints at the dose level predicted for the northern river otter during the Site C Peak scenario – no data points fall in the lower left (grey) area of the plots.

Conclusions

The dose-response data set for mammals suggests that, at the estimated Site C - Peak dose, representing maximum fish mercury concentrations within the reservoir following inundation, we would not expect effects on survival, growth or reproduction. There is moderate uncertainty in this conclusion because of the limited data available.

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Table F1. Summary of mink studies (dose is in units of methylmercury).

Study	Treatment	Sample size	Sex	Dose (mg/kg/day)	Duration (days)	Survival	Reproduction (kits/female)
Aulerich et al. 1974	Control	15	3 M, 12 F	0.000	90	100%	
	Treatment	15	3 M, 12 F	1.291	90	0%	
Chamberland et al. 1996	Control	20	F	0.019	109	95%	
	Treatment 1	20	F	0.095	109	100%	
	Treatment 2	20	F	0.171	109	75%	
Dansereau et al. 1999	Control	50	F	0.023	365	100%	1.04
	Treatment 1	50	F	0.103	365	100%	0.82
	Treatment 2	50	F	0.171	365	72%	0.08
Laperle et al. 1999	Control	50	F	0.033	90	100%	
	Treatment 1	50	F	0.166	90	100%	
	Treatment 2	50	F	0.333	90	33%	
Wobeser et al. 1976	Control	5	F	0.007	93	100%	
	Treatment 1	5	F	0.074	93	100%	
	Treatment 2	5	F	0.121	93	0%	
	Treatment 3	5	F	0.323	93	0%	
	Treatment 4	5	F	0.558	93	0%	
	Treatment 5	5	F	1.008	93	0%	
Wren et al. 1987a,b	Control	5	M	0.000	60	100%	
	Treatment	4	M	0.100	60	100%	
	Control	15	F	0.000	60	100%	4.50
	Treatment	12	F	0.180	60	25%	4.00

Table F2. Summary of otter study (dose is in units of methylmercury).

Study	Treatment	Sample size	Sex	Dose (mg/kg/day)	Duration (days)	Survival	Notes
O'Conner & Nielsen 1981	Control	2	M	0.000	200	50%	1
	Treatment 1	3	M	0.093	200	33%	2
	Treatment 2	3	M	0.170	200	0%	3
	Treatment 3	3	M	0.370	200	0%	4

Notes

1) One died but looked clinically normal
2) One surviving otter clinically normal, other 2 had signs of intoxication, died on days 179 and 159
3) Signs of intoxication, otters died on days 113, 116, and 123
4) Otters died on days 59, 48, 55

Figure F1. Methylmercury dose-response data for mammal survival, by study

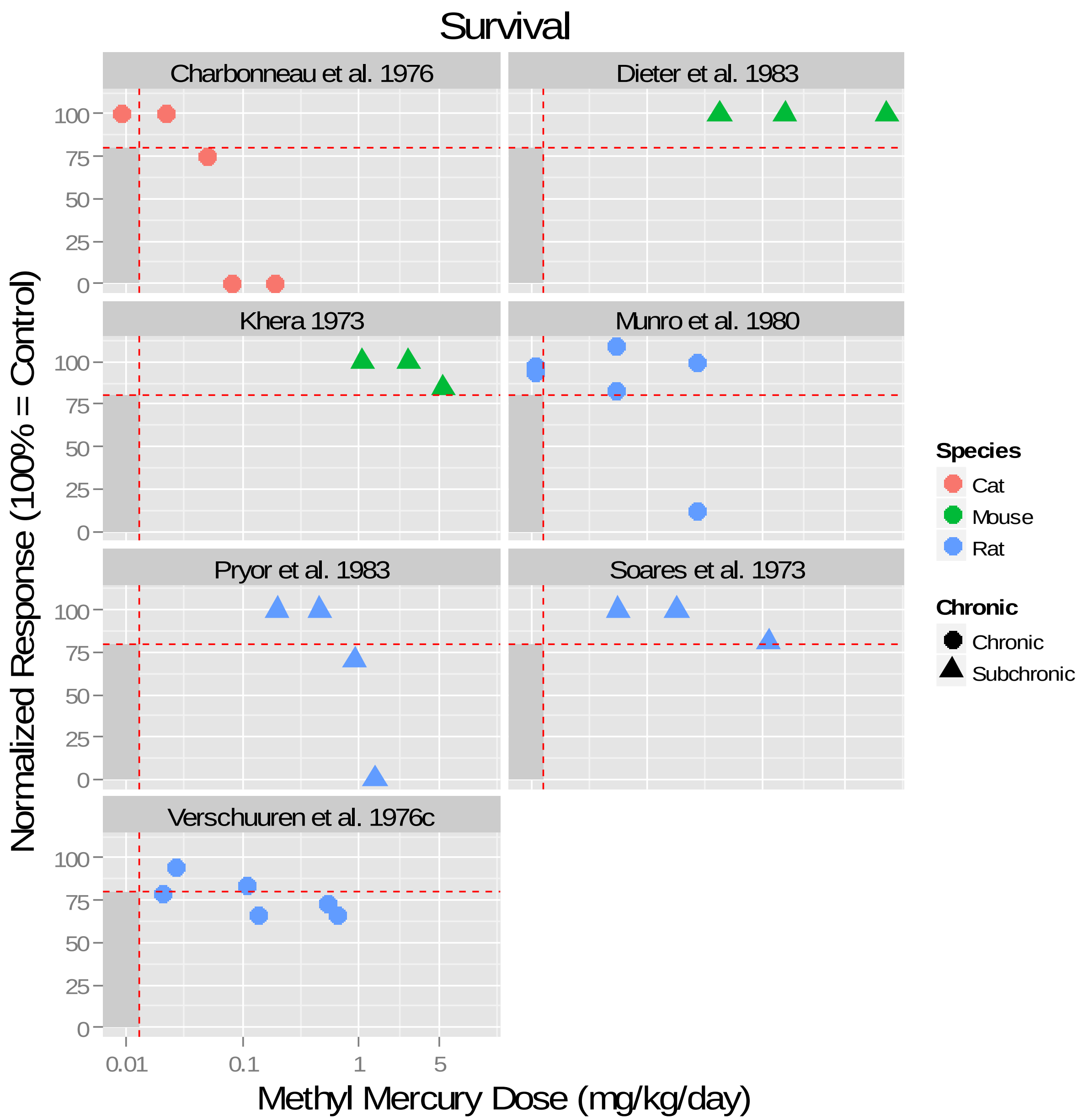

Figure F2. Methylmercury dose-response data for mammal survival, pooled across studies

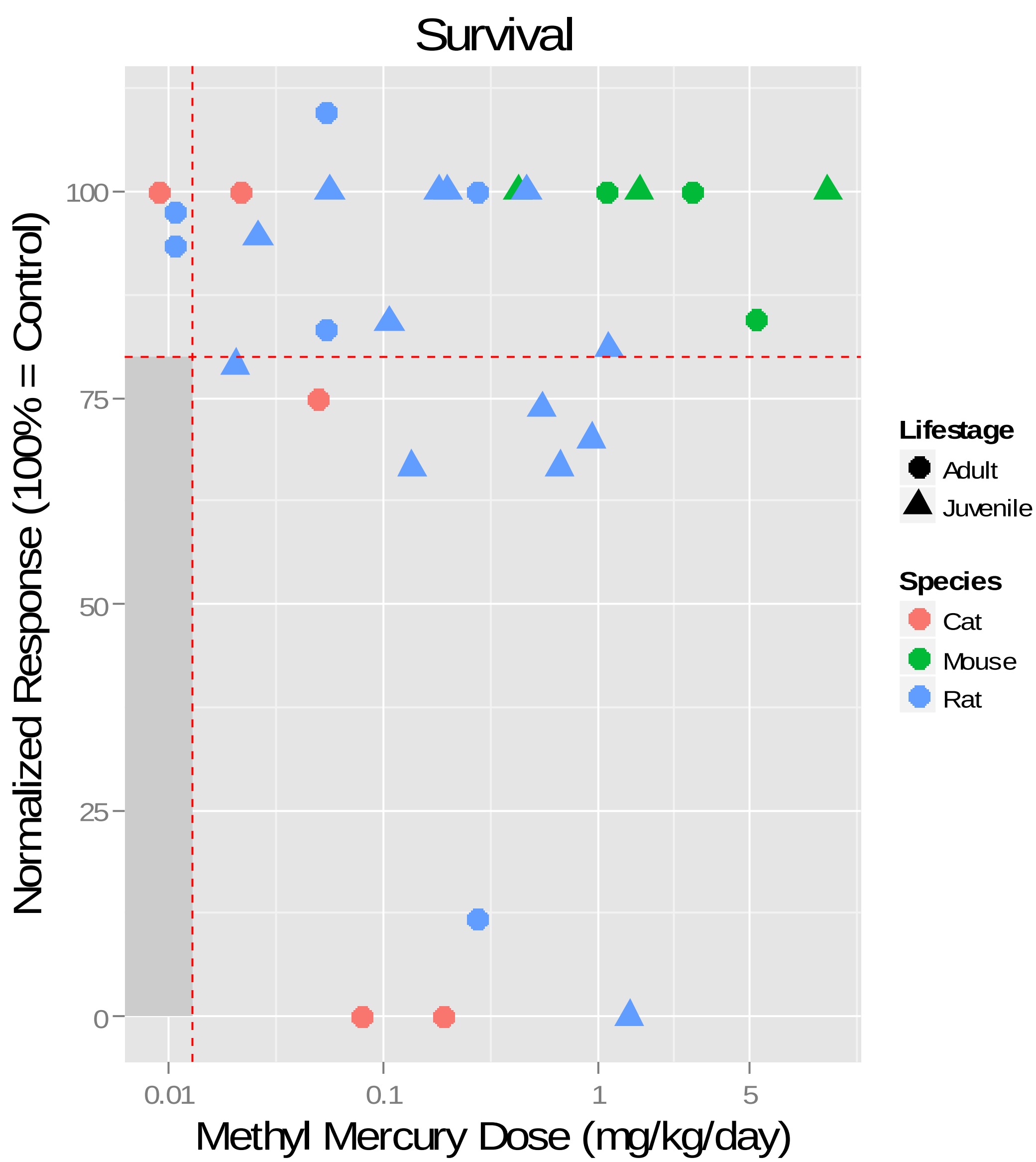

Figure F3. Methylmercury dose-response data for mammal growth, by study

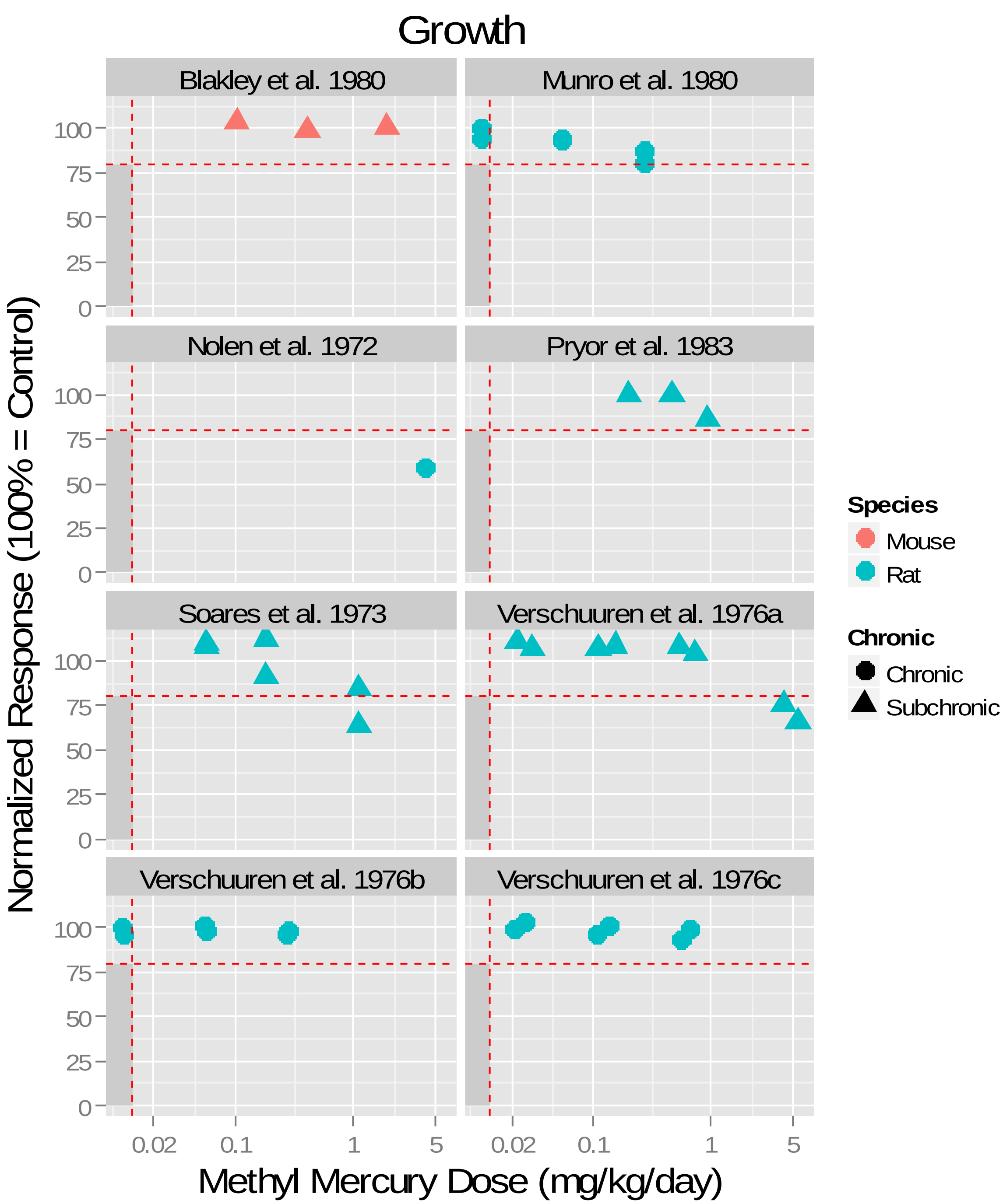

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Figure F4. Methylmercury dose-response data for mammal growth, pooled across studies

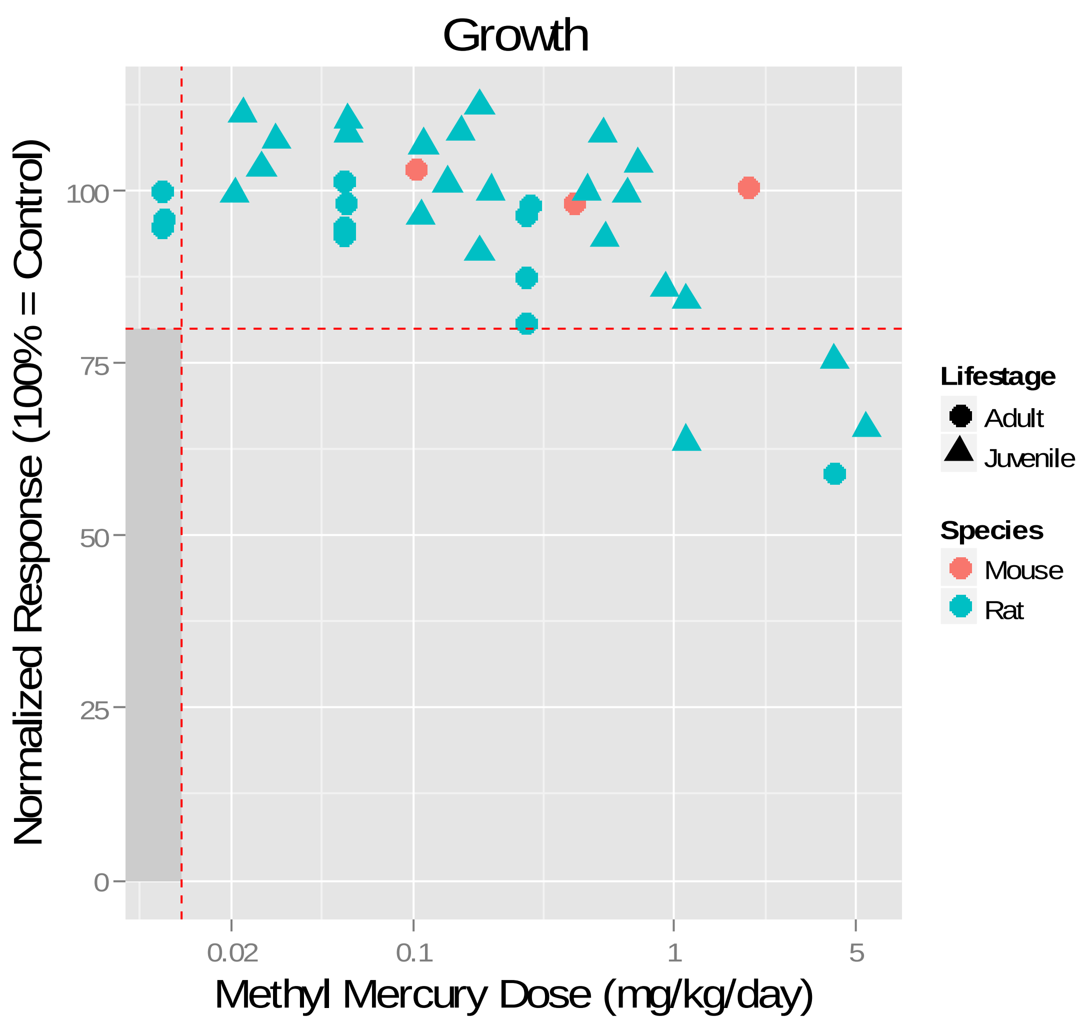

Figure F5. Methylmercury dose-response data for mammal offspring production, by study