DATABASE OF SELENIUM CONCENTRATIONS IN FISH TISSUES FROM REFERENCE SITES

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1 INTRODUCTION

The following summarizes a database of selenium (Se) concentrations measured in fish tissues collected from the United States and Canada. The objective of this Se database compilation effort and evaluation is to focus on identifying fish Se concentrations associated with reference sites that are not impacted, or minimally impacted, by anthropogenic activities that could result in the mobilization of Se into water bodies. In general, the Se data compiled here focus on concentrations measured in whole body tissue, muscle, ovaries, and eggs. Data were compiled from readily available databases, published literature, and data sets provided from North American Metals Council – Selenium Working Group (NAMC-SWG) members. Accordingly, this does not represent an exhaustive evaluation of Se concentrations in fish from background or reference sites.

Sources of fish Se data in the United States included:

- **Government databases:** National Irrigation Water Quality Program (NIWQP) and National Water Quality Assessment Program (NAWQA)

- **NAMC-SWG members:** American Electric Power (AEP), Arch Coal, Duke Energy, Monsanto Company, Simplot and Newfields, GEI Consultants, Parametrix, and the Ohio Environmental Protection Agency (as provided by Aaron Redman of Hydroqual).

- **Published and gray literature:** Finley and Garrett (2007), May et al. (2008), and Progress Energy Carolinas (2008).

Sources of fish Se data in Canada included:

- **NAMC-SWG members:** Cameco Corporation and Elk Valley Coal, which provided several of the reports listed in the following bullet

- **Published and gray literature:** Casey (2005), Casey and Siwik (2000), Golder Associates (2005, 2008), Kennedy et al. (2000), Mackay (2006), McKeown and Chapman (2005), Minnow Environmental and Paine, Ledger and Associates (2006), Muscatello et al. (2006, 2008), and Rudolph et al. (2008).

The following first summarizes each of the Se data sources included in the database, including a description of whether appropriate reference site data were available from each data source. It is generally not possible to independently verify which locations are true reference sites, so it was necessary to rely on the various data sources to identify which sites were considered reference sites.

2 UNITES STATES DATA

2.1 Government Databases

2.1.1 National Irrigation Water Quality Program, Western US (Seiler et al. 2003)

Under the National Irrigation Water Quality Program (NIWQP), field investigations were conducted at 26 sites in the western United States[1] to determine whether irrigation drainage has had harmful effects on fish, wildlife, or humans (Seiler et al. 2003). A key constituent of interest at most of these sites was Se. Samples at each site typically included surface water, bottom sediment, and tissue (aquatic plants,

[1] The sites were located in the following US states: Arizona, California, Colorado, Idaho, Kansas, Montana, New Mexico, Nevada, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

invertebrates, fish, and aquatic birds). The data compiled under the NIWQP were not based on a random sampling design and are therefore biased for the following reasons: (1) some sampling targeted areas that had a high likelihood of high contaminant concentrations and (2) some sampling targeted the main channels of large streams for comparison to historical data (Seiler et al. 2003). Accordingly, the former could lead to a high bias in contaminant concentrations measured, while the latter could lead to a low bias as contaminant concentrations in main channels of large streams would be more diluted.

The surface water sampling locations were identified in the NIWQP database as "reference sites" or "contaminated sites." The reference sites typically represented sites upstream of the study area. This does not necessarily mean that the reference site had not been impacted by anthropogenic activities upstream, which could potentially have mobilized Se into the water body, but it does mean that the reference locations are not influenced by the irrigation areas that are the focus of the NIWQP studies. Under the NIWQP, surface water Se concentrations were measured at 109 reference sites. The median Se concentration was <1 µg/L and the 75th percentile Se concentration was 2 µg/L. For those sites on or downstream of irrigated land, the median Se concentration was 2 µg/L and the 75th percentile was 15 µg/L. Fish sampling was generally opportunistic, so fish samples were not always collected in the same locations as the water samples. In some cases, the fish sampling location could be readily paired with a water sampling location, which allowed for a simple determination of whether the fish sample was from a reference site. In other cases, the original study reports needed to be reviewed to determine whether the fish sample was collected from a reference site.

Overall, whole body fish Se concentrations under the NIWQP are available for 2,177 samples[2]. The 10th, 25th, 50th, 75th, and 90th percentile whole body Se concentrations are 1.4, 2.2, 3.9, 7.3, and 13 µg/g dry wt.[3], respectively. The cumulative distribution of whole body Se concentrations is provided in Figure 1 and compared to recommended whole body Se guidelines of 4 µg/g (Lemly 2002, Hamilton 2002), 7.91 µg/g (USEPA 2004), and 9 µg/g (DeForest et al. 1999). As shown, approximately 48%, 22%, and 18% of the whole body fish Se concentrations exceed the recommended guidelines of 4, 7.91, and 9 µg/g, respectively. For whole body fish Se concentrations associated with reference sites (i.e., the sites upstream of the irrigation sites being evaluated in each study), the 10th, 25th, 50th, 75th, and 90th percentile whole body Se concentrations are 1.1, 1.6, 2.4, 3.8, and 7.2 µg/g, respectively. The cumulative distribution of whole body Se concentrations associated with reference sites is shown in Figure 2. Approximately 24%, 9%, and 7% of the whole body Se concentrations at reference sites exceed the guidelines/criteria of 4, 7.91, and 9 µg/g, respectively.

Skorupa et al. (1998) stated the background Se concentration in fish range from <1 to 4 µg/g. The reference cite data from the NIWQP studies generally support this range, as 76% of the whole body fish samples had a Se concentration of ≤4 µg/g. The reference fish samples with whole body Se concentrations ≥5 µg/g were collected from eight study areas, with 51% if the samples collected from the Gunnison and Uncompahgre River Basins (Colorado) and 17% of the samples collected from the Cheyenne River in the Angostura Reclamation Unit (Wyoming). Accordingly, the reference site samples with whole body Se concentrations ≥5 µg/g were heavily weighted by these locations.

2.1.2 National Water Quality Assessment (2008) (http://water.usgs.gov/nawqa/)

The United States Geological Survey (USGS) began the NAWQA program in 1991, with environmental samples collected from basins across the United States. Fish samples for Se analysis were collected from streams identified as reference sites were from Alaska, Arizona, California, Oregon, Washington, and

[2] The NIWQP field investigations were largely conducted in the late 1980s and early 1990s. The data from these field investigations were later synthesized and discussed in Seiler et al. (2003). The data are now available on-line at http://www.usbr.gov/niwqp/datasynthesis/index.html.

[3] All concentrations reported in this technical memorandum are on a dry weight basis, unless otherwise noted.

Wyoming. Figure 3 provides a cumulative distribution of whole body fish Se concentrations measured at reference sites, which ranged from 0.9 to 8.47 µg/g. As shown, approximately 40%, 6%, and 0% of the whole body Se concentrations in reference site fish exceed the Se guidelines of 4, 7.9, and 9 µg/g, respectively.

2.2 NAMC-SWG Members

2.2.1 American Electric Power (2008)

American Electric Power (AEP) provided ovary and Se concentrations in bluegill (*Lepomis macrochirus*) and longear sunfish (*Lepomis megalotis*) collected from reference sites in Campaign Creek (a tributary to the Ohio River) and the mainstem of the Ohio River. These data were originally published in Reash et al. (2006) and Lohner et al. (2001). Liver Se concentrations ranged from 0.95 to 7.41 µg/g (n=15) and averaged 4.1 µg/g. Ovary Se concentrations ranged from 1.67 to 5.16 µg/g (n=4) and averaged 3.38 µg/g. These ovary Se concentrations are below the egg/ovary Se guideline of 10 µg/g recommended by Lemly (2002) and the ovary Se guideline of 17 µg/g recommended by DeForest et al. (1999).

2.2.2 Arch Coal (2006)

Arch Coal provided whole body fish Se data from West Virginia streams and lakes in 2006. Whole body fish Se concentrations from reference streams were <1 and 2.18 µg/g for creek chub (*Semotilus atromaculatus*) and stoneroller (*Campostoma* sp.) at Ash Fork and <1 µg/g for stoneroller collected from Sycamore Creek. For comparison, whole body fish Se concentrations at impacted sites ranged from <1 to 37.4 µg/g. Whole body Se concentrations at the reference sites were all below the lowest recommended whole body Se guideline of 4 µg/g.

2.2.3 Duke Energy (2008)

Duke Energy provided muscle Se concentrations in fish collected from a reference site in the Dan River, North Carolina (at US Highway 311) from 1990-2007 (Duke Energy 2008). This site is located 4.3 km upstream of an ash pond outfall and serves as a reference location for the facility. The fish species that have been collected are redbreast sunfish (*Lepomis auritus*), golden redhorse (*Moxostoma erythrurum*), V-lip redhorse (*Moxostoma pappillosum*), snail bullhead (*Ameiurus brunneus*), and flat bullhead (*Ameiurus platycephalus*). Figure 4 provides cumulative distributions of muscle Se concentrations in each species from 1990-2007. Dry weight concentrations were estimated from wet weight concentrations assuming 75% moisture. As an approximation, muscle Se concentrations were compared to whole body Se guidelines. With one exception, all muscle Se concentrations were below the whole body Se guideline of 4 µg/g.

2.2.4 Monsanto Company (2008)

Monsanto provided whole body Se concentrations for forage fish (e.g., sculpins [Family Cottidae]) and muscle Se concentrations for salmonids (e.g., Yellowstone cutthroat trout [*Oncorhynchus clarki bouvieri*]) collected from the Blackfoot Reservoir and several streams in southeastern Idaho. The reference sites identified in the data provided were Meadow Creek (above the Blackfoot Reservoir), the Blackfoot Reservoir delta at Meadow Creek, Timber Creek, and Stewart Creek. Figure 5 provides cumulative distributions of whole body and muscle Se concentrations in forage fish and salmonids, respectively, collected from reference sites. Whole body Se concentrations in forage fish ranged from 1.4 to 10 µg/g and muscle Se concentrations in salmonids ranged from 0.86 to 5.8 µg/g. Approximately 40%, 7%, and 7% of the whole body Se concentrations in reference site forage fish exceed the Se guidelines of 4, 7.9, and 9 µg/g, respectively.

2.2.5 Simplot and Newfields (2008)

Simplot, via Sean Covington of Newfields, also provided fish Se data from southeastern Idaho. These data represent a compilation of fish sampling events conducted by Simplot, Idaho Fish and Game, and the

Greater Yellowstone Coalition (GYC) in 2007. A portion of the samples were collected from "background" sites (Brush Creek, Crow Creek, Deer Creek, Diamond Creek, Left Fork Georgetown Creek, Johnson Creek, Miner Creek, Rawlins Creek, and Slug Creek) or "control" sites (Boulder Creek, Browns Creek, South Fork Deer Creek, Horse Creek, Stump Creek, Timber Creek, and South Fork Tincup). Background sites are in non-impacted stream segments that flow through the Se-rich Phosphoria Formation and control sites are in non-impacted stream segments that do not flow through the Se-rich Phosphoria Formation. The fish species collected were brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), Yellowstone cutthroat trout (*O. clarki bouvieri*), and sculpin (Cottidae). Figure 6 shows the cumulative distributions of whole body Se concentrations in fish collected from reference and control sites (all fish species combined). The whole body Se concentrations are higher in the reference site fish than in the control fish, with the median concentrations being 4.1 and 2.8 µg/g, respectively. Approximately 55% of the whole body Se concentrations in reference site fish exceed the Se guideline of 4 µg/g, while less than 4% of the whole body Se concentrations exceed the guidelines of 7.9 and 9 µg/g. For the control fish, all whole body Se concentrations are below the guidelines of 7.9 and 9 µg/g, but approximately 24% of the concentrations exceed the guideline of 4 µg/g.

2.2.3 GEI Consultants (2007, 2008)

GEI Consultants, via Steve Canton, provided fish Se data from field studies they have conducted in Colorado and Texas. The Colorado data did not include any true reference sites, but the Texas data included Rock Creek and White Deer Creek as reference sites (Baker, personal communication). Figure 7 provides cumulative distributions of whole body Se concentrations in fish from Rock Creek and White Deer Creek, which species include centrarchids (green sunfish [*Lepomis macrochirus*], long-eared sunfish [*L. megalotis*], smallmouth bass [*Micropterus dolomieui*]), cyprinids (carp [*Cyprinus carpio*], suckermouth minnows [*Phenacobius mirabilis*], red shiners [*Cyprinella lutrensis*]), and western mosquitofish (*Gambusia affinis*) and plains killifish (*Fundulus zebrinus*). Whole body Se concentrations ranged from 2.0 to 6.2 µg/g. Approximately 25%, 0%, and 0% of the whole body Se concentrations in these reference site fish exceed the Se guidelines of 4, 7.9, and 9 µg/g, respectively.

2.2.4 Parametrix (2005)

Parametrix developed a database of Se concentrations in fish tissue and other media from water bodies in Colorado. These data were compiled from a variety of sources, including the NIWQP, the USGS's National Water Information System (NWIS) database, the USEPA's STOrage and RETrieval (STORET) database, the U.S. Fish and Wildlife Service's (USFWS) Westwide Study, and various other data holders (e.g., municipalities, industries). However, with the exception of the data from the NIWQP, which was discussed separately above, it is unknown which samples could be clearly defined as reference sites. Accordingly, the Colorado data compiled in Parametrix (2005) was not included in this evaluation of background Se concentrations.

2.2.5 Ohio Environmental Protection Agency (1998)

Ohio EPA (1998) reported whole body Se concentrations in carp species and muscle Se concentrations in smallmouth bass collected from the Ottawa River Basin in 1996. Whole body Se concentrations measured in two reference samples were approximately 0.9 and 1.0 µg/g in carp spp., and approximately 1.0 and 1.5 µg/g in the muscle of smallmouth bass.

2.3 Published and Gray Literature

2.3.1 May et al. (2008)

May et al. (2008) measured Se concentrations in water, sediment, macroinvertebrates, and fish collected from the Solomon River Basin in Kansas. The Solomon River Basin is underlain by marine geological shales high in Se and consists primarily of farms and ranches in north-central Kansas. May et al. (2008) do not explicitly state whether any of their sampling locations can be considered background or reference sites, but some inferences can be made. Two reservoirs (Kirwin and Webster) provide water for

irrigation, municipal, industrial, and domestic use; the Bureau of Reclamation's (BOR) irrigation districts do not provide water for irrigation upstream Kirwin and Webster Reservoirs. In addition, May et al. (2008) mapped the locations in the basin that are benefited by irrigation units, which allows for the identification of sampling locations that are presumably not significantly impacted by these irrigation units. Accordingly, fish sampling locations identified as background sites for the Solomon River Basin were the Kirwin Reservoir (Site 1), the North Fork of the Solomon River downstream of Kirwin Reservoir (Site 2), and the South Fork of the Solomon River at the gauging station near Woodston (Site 28). The mean whole body Se concentrations in common carp (*C. carpio*) and red shiner (*C. lutrensis*) were 7.78 and 7.03 µg/g at Site 1, 9.33 and 5.81 µg/g at Site 2, and 10.4 and 10.0 µg/g at Site 28. For comparison, mean whole body Se concentrations in common carp and red shiners at sites within and downstream of lands benefited by irrigation units ranged from 7.16 to 11.2 µg/g. Accordingly, mean whole body Se concentrations at Sites 1, 2, and 28 are slightly below or within the range of contaminant concentrations at downstream irrigated sites. The mean background Se concentrations in whole body fish all exceed the guideline of 4 µg/g, and are similar to the guidelines of 7.91 and 9 µg/g. May et al. (2008) measured the weights of the four most prevalent fish species in the basin (channel catfish [*Ictalurus punctatus*], common carp [*C. carpio*], green sunfish [*L. cyanellus*], bluegill [*L. macrochirus*]), which, according to the authors, showed the presence of some very small fish, with some in significant numbers. The Se concentrations in these fish clearly exceeded the guideline of 4 µg/g. May et al. (2008), however, caution that fish population studies are needed to truly understand whether they are being affected by Se.

2.3.2 Finley and Garrett (2007)

Finley and Garrett (2007) summarized fish Se concentrations in Belews Lake and Hyco Reservoir following recovery of fish populations, so the data they present are not truly from a reference site. However, the fish populations are now successfully reproducing. Whole body Se concentrations in fish from Hyco Reservoir and Belews Lake (estimated from muscle Se per USEPA [2004]) shortly after fish populations recovered (1992-1996) and in recent years (2003-2006) were reported. In Hyco Reservoir, median whole body Se concentrations in catfish, bluegill, and largemouth bass were approximately 24, 19, and 17 µg/g shortly after recovery and approximately 6, 8, and 7 µg/g from 2003-2005. In Belews Lake, median whole body Se concentrations in carp, redear sunfish, and crappie were approximately 22, 17, and 18 µg/g shortly after recovery and approximately 9, 10, and 9 µg/g from 2004-2006. Thus, recovery of fish populations in these water bodies was associated with whole body Se concentrations that were still greater than 15 µg/g, and which have subsequently declined further to approximately 6 to 10 µg/g. These levels are greater than or comparable to the guidelines of 4, 7.9, and 9 µg/g recommended by Lemly (2002), USEPA (2004), and DeForest et al. (1999), respectively.

2.3.3 Progress Energy Carolina (2008)

The Mayo Reservoir (North Carolina) reached full-pool elevation and the Mayo Steam Electric Plant began commercial operations in 1983. Environmental monitoring of water, sediments, and aquatic organisms has occurred since that time. Effects of the power plant discharge on aquatic organisms have been minimal and primarily confined to the area nearest the ash pond discharge. Overall, the monitoring report states that the reservoir supports a biological community typical of an oligotrophic southeastern reservoir. The fish community is dominated by sunfish and bluegill (*L. macrochirus*) is the dominant species. Bluegill and largemouth bass (*Micropterus salmoides*) reproduction was evidently successful throughout the reservoir and there was no indication of missing year classes. Selenium concentrations in fish muscle collected from Mayo Reservoir are summarized in Table 1. As for Hyco Reservoir and Belews Lake following recovery, the Mayo Reservoir cannot be considered a reference site, particularly near the plant discharge; however, the data do provide an example of fish populations not being impacted by Se despite fish Se concentrations exceeding the whole body Se guideline of 4 µg/g.

3 CANADIAN DATA

3.1 NAMC-SWG Members

3.1.1 Cameco (2007)

Cameco provide fish Se data from 1991 through 2006, which were collected from northern Saskatchewan. The following water bodies or sampling locations were identified as reference sites (Webster, personal communication and Stark, personal communication): Cigar Lake, inflows within Read Lake, Lake Athabasca, Longyear Bay, Lower Read Lake, Read Lake, Toby Lake, and Zimmer Lake. Given the size of Lake Athabasca and that the samples collected were far-field samples, the Se concentration data for this sampling location is as close to background as available (Webster, personal communication). The fish species sampled were lake chub (*Couesius plumbeus*), lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), longnose sucker (*Catostomus catostomus*), northern pike (*Esox lucius*), spottail shiner (*Notropis hudsonius*), and white sucker (*Catastomus commersonii*). Whole body fish Se concentrations in inflows to Read Lake, Lake Athabasca, and Zimmer Lake ranged from 2.0-3.6, 0.6-16, and 4.0-7.6 µg/g, respectively. Muscle Se concentrations in the remaining reference sites ranged from 0.28 to 4.8 µg/g. (All dry weight whole body and muscle Se concentrations were estimated from wet weight Se concentrations assuming 75% moisture.) Figure 8 provides cumulative distributions of whole body and muscle Se concentrations measured in the reference site fish. As shown, approximately 34%, 9%, and 9% of the whole body Se concentrations in reference site fish exceed the Se guidelines of 4, 7.9, and 9 µg/g, respectively.

3.1.2 Elk Valley Coal (now Teck Coal)

Elk Valley Coal has conducted numerous studies that have been either published or summarized in reports. These specific reports are included in the following section.

3.2 Published and Gray Literature

3.2.1 Casey and Siwik (2000)

Casey and Siwik (2000) reported muscle and egg Se concentrations in rainbow trout (*Oncorhynchus mykiss*) collected from the McLeod River Basin and Fairfax Lake in the north east slopes region of Alberta. Reference sites sampled were Fairfax Lake, Wampus Creek (near mouth), and Whitehorse Creek (near mouth). The cumulative distribution of muscle Se concentrations in reference site rainbow trout is shown in Figure 7, with concentrations ranging from <1 to 4.92 µg/g. Although it is unknown how these muscle Se concentrations would compare to whole body Se concentrations, they are compared to the whole body Se guidelines of 4, 7.91, and 9 µg/g for a rough comparison. As shown in Figure 9, approximately 30% of the muscle Se concentrations exceed the whole body Se guideline of 4 µg/g, but none exceed the whole body guidelines of 7.91 or 9 µg/g. The cumulative distribution of Se concentrations in reference site rainbow trout eggs is provided in Figure 10. The egg Se concentrations are compared to an egg/ovary guideline of 10 µg/g recommended by Lemly (2002) and the ovary guideline of 17 µg/g recommended by DeForest et al. (1999). Approximately 26% of the egg Se concentrations exceed the guideline of 10 µg/g, but none exceed the guideline of 17 µg/g. The basis for very high egg Se concentrations of 35 to 64 µg/g is unclear. These samples were collected from the mouth of Whitehorse Creek, perhaps suggesting that the fish had a higher Se exposure in another water body.

3.2.2 Golder Associates (2005)

Golder Associates (2005) reported Se concentrations in the muscle and ovaries of fish collected in Elk Valley, British Columbia, including a reference site (Elk River near Osborne Creek). Muscle Se concentrations in cutthroat trout (*Oncorhynchus clarki*) and mountain whitefish (*Prosopium williamsoni*) were 5 and 4.6 µg/g, respectively, and ovary Se concentrations were 9 and 21 µg/g in cutthroat trout and

mountain whitefish, respectively. The ovary Se concentration in cutthroat trout is less than the ovary guidelines of 10 and 17 µg/g recommended by Lemly (2002) and DeForest et al. (1999), but the mountain white fish ovary Se concentration exceeds the Lemly guideline by approximately a factor of two and the DeForest et al. guideline by a factor of approximately 0.25.

3.2.3 Golder Associates (2008)

Golder Associates (2008) reported whole body Se concentrations in lake chub (*C. plumbeus*) and spottail shiners (*N. hudsonius*) collected from reference sites in northern Saskatchewan. All whole body Se concentrations were less than or equal to 2.8 µg/g and, therefore, below all recommended whole body Se guidelines (Figure 11).

3.2.4 Kennedy et al. (2000)

Cutthroat trout (*Oncorhynchus clarki lewisi*) were collected from the Fording River (a Se exposed site) and Connor Lake (a reference site) in southeastern British Columbia. The mean Se concentration in reference site fish was 2.4 µg/g, with a range of 1.4 to 3.8 µg/g. The mean egg Se concentration in reference site fish was 4.6 µg/g, with a maximum of approximately 7 µg/g. These concentrations fall below recommended tissue Se guidelines.

3.2.5 Mackay (2006)

Mackay (2006) reported muscle and ovary Se concentration in fish collected from the upper McLeod and Smoky River systems in the north east slopes region of Alberta. The reference sites sampled were Cold Creek, Deerlick Creek, Fairfax Lake, Mackenzie Creek, Muskeg River, and Whitehorse Creek. Muscle Se concentrations in brook trout (*S. fontinalis*), bull trout (*Salvelinus confluentus*), rainbow trout (*O. mykiss*), and mountain whitefish (*P. williamsoni*) ranged from <1 to 11 µg/g dry wt. (assuming 75% moisture). Although it is unknown how these muscle Se concentrations would compare to whole body Se concentrations, they are compared to the whole body Se guidelines of 4, 7.91, and 9 µg/g in Figure 12 for a rough comparison. As shown, approximately 16%, 4.5%, and 2% of the muscle Se concentrations exceed the whole body Se guidelines of 4, 7.91, and 9 µg/g, respectively. The cumulative distribution of ovary Se concentrations in rainbow trout fish is provided in Figure 13. Ovary Se concentrations ranged from 1.3 to 61 µg/g dry wt. in reference site fish (assuming 67% moisture). Approximately 60% and 45% of the ovary Se concentrations exceeded the Lemly (2002) ovary Se guideline of 10 µg/g and DeForest et al. (1999) guideline of 17 µg/g, respectively. The ovary Se concentrations greater than the guideline of 17 µg/g were all measured in fish from Mackenzie Creek or Whitehorse Creek. Mackay (2006) discussed that both of these creeks drain into the McLeod River (a Se exposed site) and that upstream migration of rainbow trout occur in spring prior to spawning; however, the fish with elevated ovary Se levels were collected in mid-October when rainbow trout are not expected to undergo upstream spawning migrations. Nevertheless, it appears possible that fish collected from reference sites with high ovary Se concentrations may have a previous Se exposure history unrelated to these reference sites.

3.2.6 McKeown and Chapman (2005)

McKeown and Chapman (2005) reported whole body Se concentrations in fish collected from the Lower and Upper McLeod River and Mackenzie Creek in 2005. Mackenzie Creek is a reference site not affected by mining activities, but it could be in the future. Whole body Se concentrations in rainbow trout (*O. mykiss*) collected from Mackenzie Creek ranged from 6.1 to 9.3 µg/g, which all exceed the whole body Se guideline of 4 µg/g and are slightly below or above the whole body Se guidelines of 7.91 and 9 µg/g.

3.2.7 Minnow Environmental and Paine, Ledge and Associates (2006)

Longnose suckers (*C. catostomus*) were collected from Goddard Marsh (a Se exposed site) and an upper Elk River oxbow (a reference site) in Elk Valley, British Columbia. Selenium concentrations in the eggs and ovaries of reference site fish ranged from 6.0-12.2 µg/g and 5.6-11.3 µg/g, respectively. Two of the 10 samples had ovary and egg Se concentrations exceeding the egg/ovary guideline of 10 µg/g

recommended by Lemly (2002), but all concentrations were less than the guideline of 17 µg/g recommended by DeForest et al. (1999).

3.2.8 Muscatello et al. (2006, 2008)

Muscatello et al. (2006) collected northern pike (*E. lucius*) from a reference site (Davies Creek) in northern Saskatchewan. The mean muscle and egg Se concentrations were 1.64 and 3.19 µg/g, respectively. Muscatello et al. (2008) collected northern pike and spottail shiner (*N. hudsonius*) from a nearby reference site, David Lake, and measured mean whole body Se concentrations of 0.78 and 0.87 µg/g, respectively. All of the tissue Se concentrations are below recommended Se guidelines.

3.2.9 Rudolph et al. (2008)

Rudolph et al. (2008) collected adult westslope cutthroat trout (*O. clarki lewisi*) from a reference site (O'Rourke Lake) and a site with elevated Se levels (Clode Pond) in southeastern British Columbia. O'Rourke Lake is an alpine lake with no connection to coal mines or the influence of the mines (Jones, personal communication). From 13 egg samples collected at the reference site, egg Se concentrations ranged from 12.3 to 16.7 µg/g. All of the egg Se concentrations were greater than Lemly's (2002) guideline of 10 µg/g, but all were less than the guideline of 17 µg/g recommended by DeForest et al. (1999). Muscle Se concentrations ranged from 6.6 to 8.7 µg/g at the reference site, which, for comparative purposes, exceed the whole body guideline of 4 µg/g, but are lower than the guideline of 9 µg/g.

4 DATA SYNTHESIS, SUMMARY, AND CONCLUSIONS

All of the reference site data discussed above were pooled to develop cumulative distributions of whole body Se (Figure 14, n=920), muscle Se (Figure 15, n=403), egg Se (Figure 16, n=52), and ovary Se (Figure 17, n=47). The 50th and 90th percentile Se concentrations were 2.9 and 6.8 µg/g for whole body, 1.6 and 4.8 µg/g for muscle, 8.6 and 15.2 µg/g for eggs, and 9.4 and 24.0 µg/g for ovaries. As discussed earlier, the data compiled and presented here do not represent a random sample of Se concentrations across the United States and Canada, but rather areas that were specifically targeted because they lie on geological formations known to have elevated Se levels. The reference sites identified in this analysis were identified as such in the original data sources and were not independently verified. The background sites identified in the NIWQP database were upstream of the specific irrigation area of interest, but it is unclear if the upstream areas were significantly impacted by anthropogenic activities that could have mobilized Se from geological formations. It is also possible that highly mobile fish species could have been exposed to elevated Se in one reach, but then moved to an upstream (background) reach.

The 90th percentile whole body Se concentration of 6.8 µg/g is greater than the guideline of 4 µg/g recommended by Lemly (2002), but is less than both the USEPA's current draft Se criterion of 7.91 µg/g and the threshold of 9 µg/g recommended by DeForest et al. (1999). The 90th percentile egg Se concentration of 15.2 µg/g is greater than the egg Se guideline of 10 µg/g recommended by Lemly (2002), but less than the analogous ovary-based guideline of 17 µg/g recommended by DeForest et al. (1999). The 90th percentile ovary Se concentration of 24.0 µg/g is greater than both Lemly's guideline of 10 µg/g and DeForest et al.'s recommended guideline of 17 µg/g. The highest ovary and egg Se concentrations measured at reference sites were from Mackenzie and Whitehorse Creeks in the north slopes region of Alberta. As discussed by Mackay (2006), upstream migration of rainbow trout from Se exposed sites to these creeks does occur for spawning, although it is unclear if the fish with the high Se concentrations had migrated since most of the high concentrations were measured in the fall. Nevertheless, if the egg and ovary Se data from these creeks are removed from the datasets, the revised 50th and 90th percentile Se concentrations are 8.0 and 14.9 µg/g for eggs and 6.7 and 10.0 µg/g for ovaries. These 90th percentile egg and ovary Se concentration still equal or exceed Lemly's recommended guideline of 10 µg/g, but not the recommended guideline of 17 µg/g from DeForest et al. (1999).

The above evaluation demonstrates that the fish tissue Se guidelines recommend by Lemly (2002) are overly conservative for regions of the United States and Canada with naturally elevated Se levels at reference or background sites. The draft whole body Se criterion developed by the USEPA and those guidelines recommended by DeForest et al. (1999) appear to be reasonable values that would not unnecessarily identify background areas as having unacceptable Se levels for fish populations.

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FIGURES

Figure 1. Cumulative distribution of whole body selenium concentrations in fish. Data from the USGS's NIWQP Data-Synthesis Database (all data, n=2177)

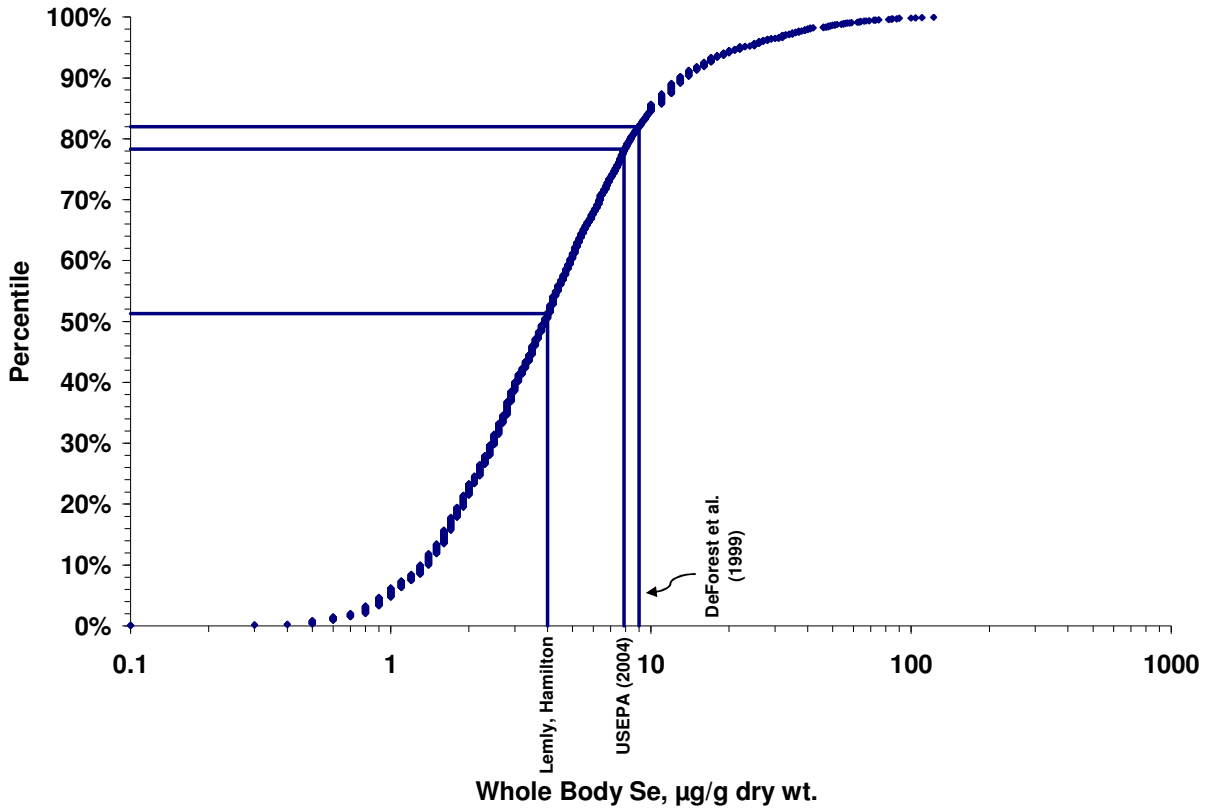


Figure 2. Cumulative distribution of whole body selenium concentrations in fish. Data from the USGS's NIWQP Data-Synthesis Database (reference site data, n=447)

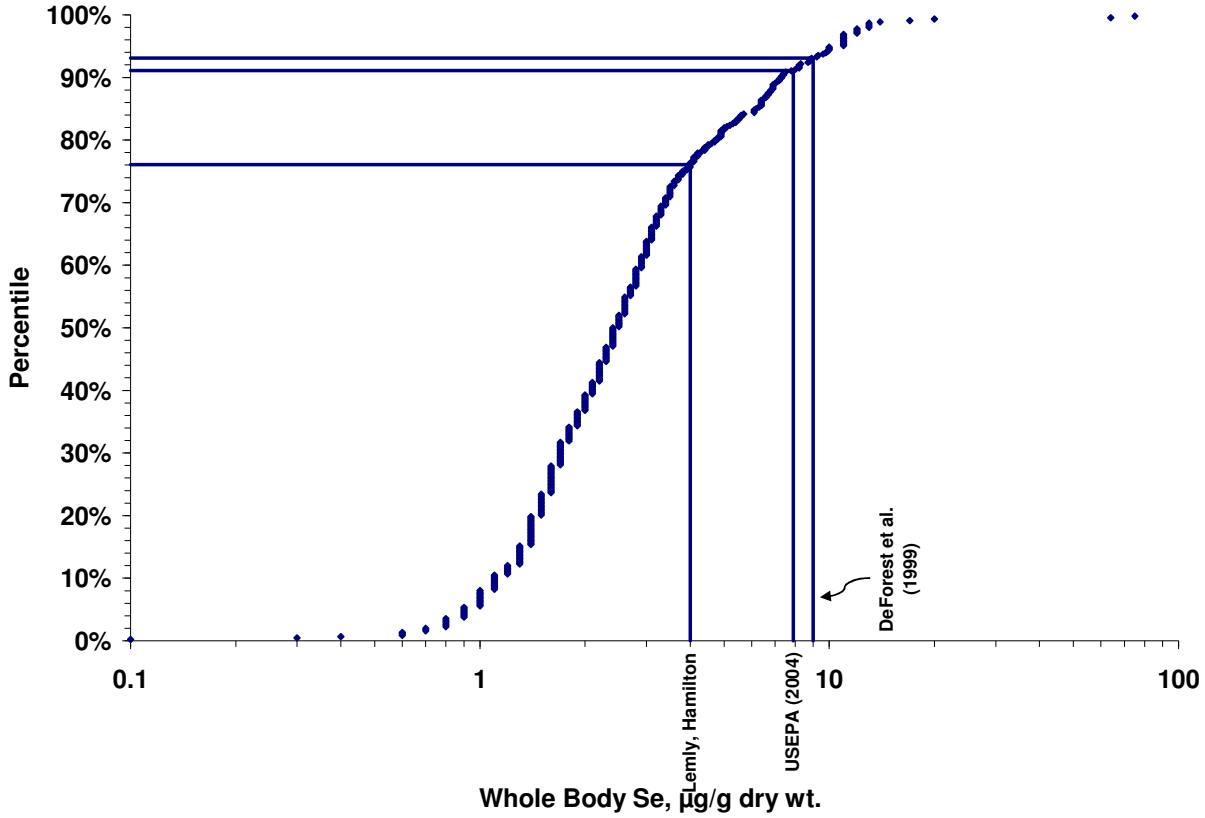


Figure 3. Cumulative distribution of whole body selenium concentrations in fish from reference sites. Data from the USGS's NAWQA Program (n=21)

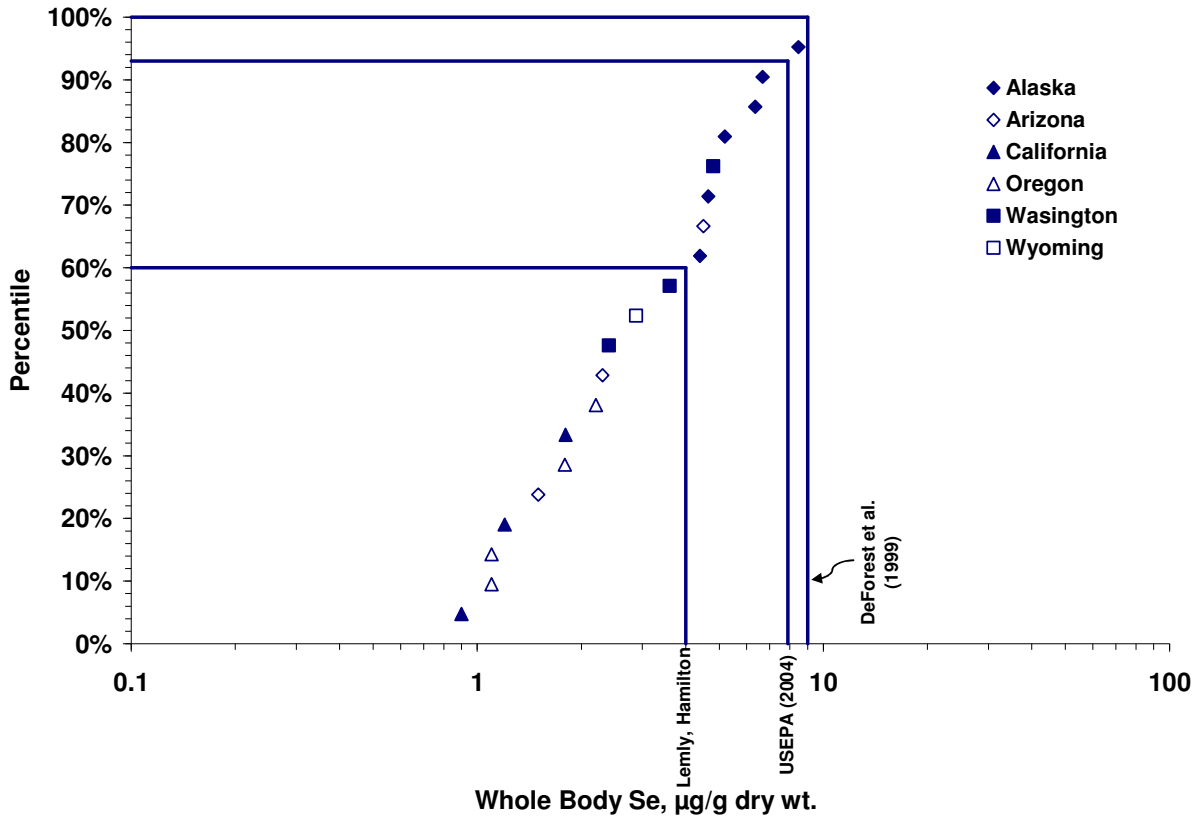


Figure 4. Cumulative distributions of muscle selenium concentrations in fish from a reference site in the Dan River, North Carolina. Data from Duke Energy (2008).

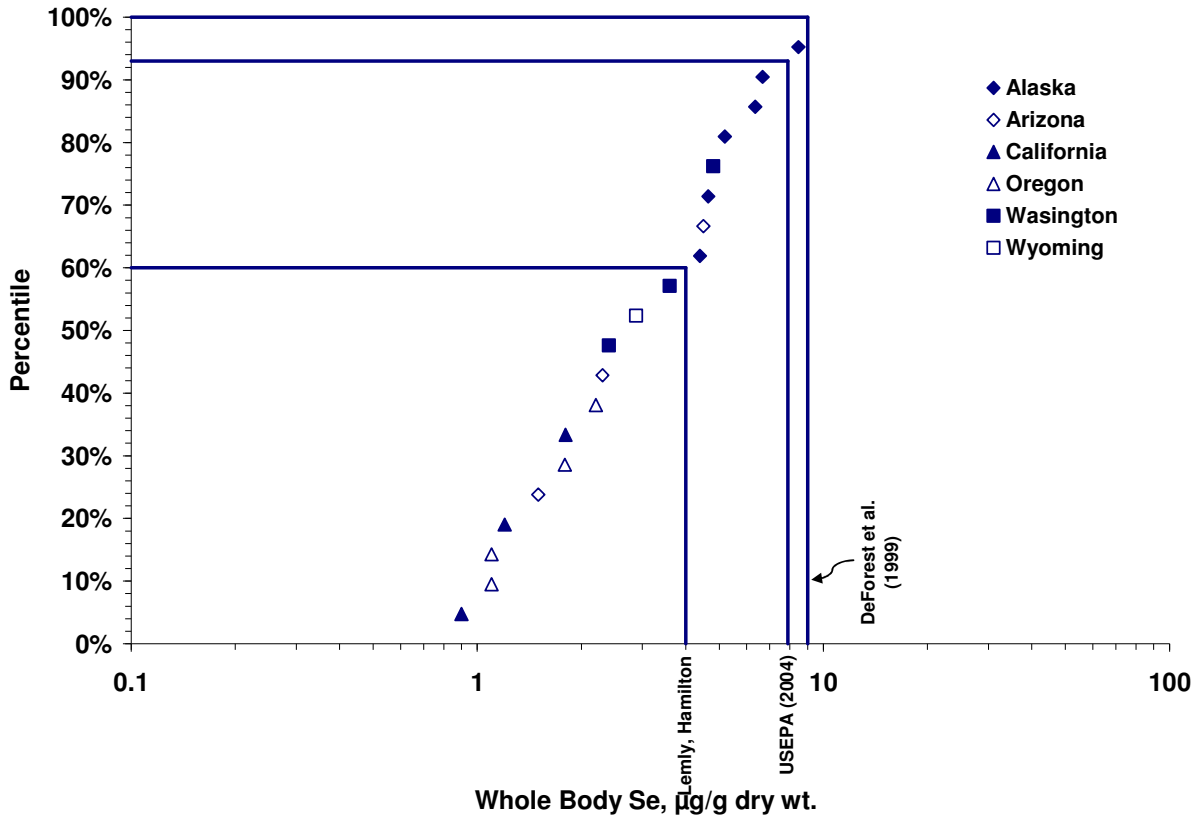


Figure 5. Cumulative distribution of whole body and muscle selenium concentrations in fish from reference sites in southeastern Idaho. Data from Monsanto (2008).

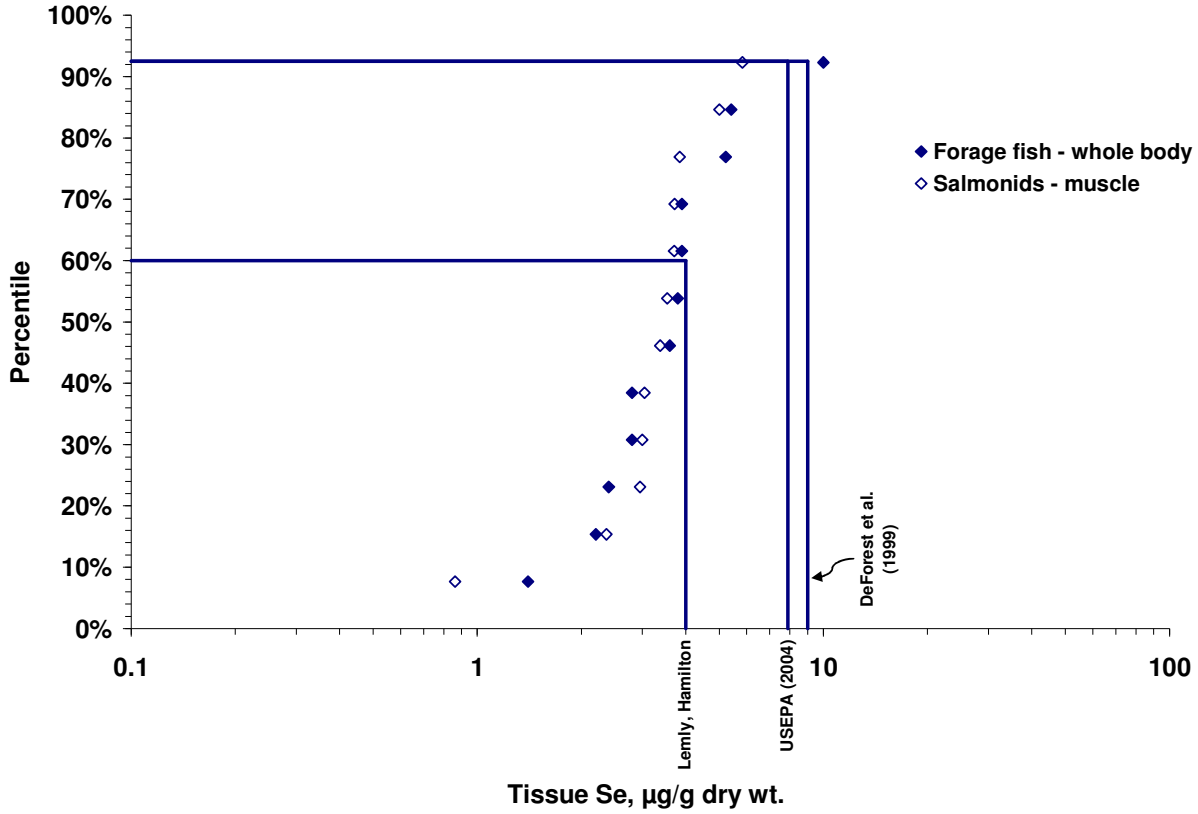


Figure 6. Cumulative distribution of whole body selenium concentrations in fish from reference and control sites (see text) in southeastern Idaho. Data collected by Simplot, Idaho Fish and Game, and the Greater Yellowstone Coalition and supplied by Simplot and Newfields (2008).

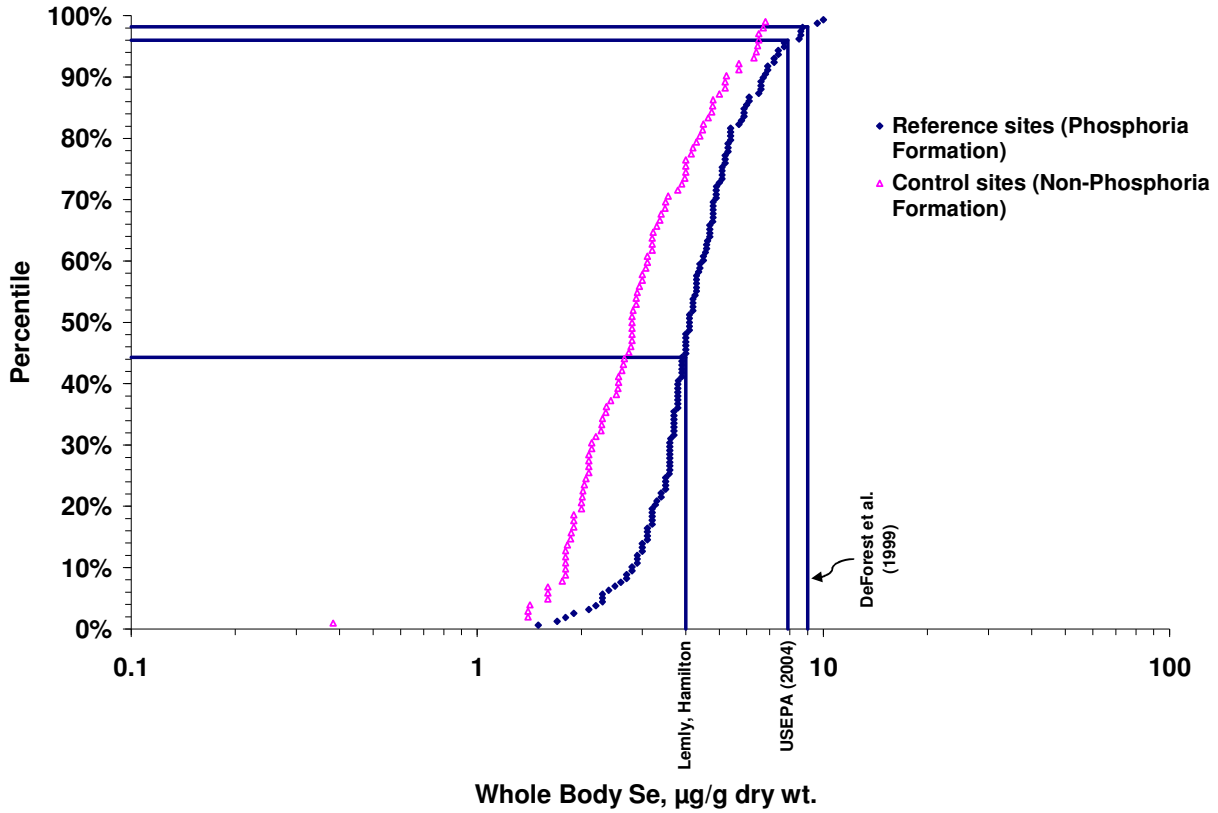


Figure 7. Cumulative distribution of whole body selenium concentrations in fish from reference sites in northern Texas. Data from GEI Consultants (2008).

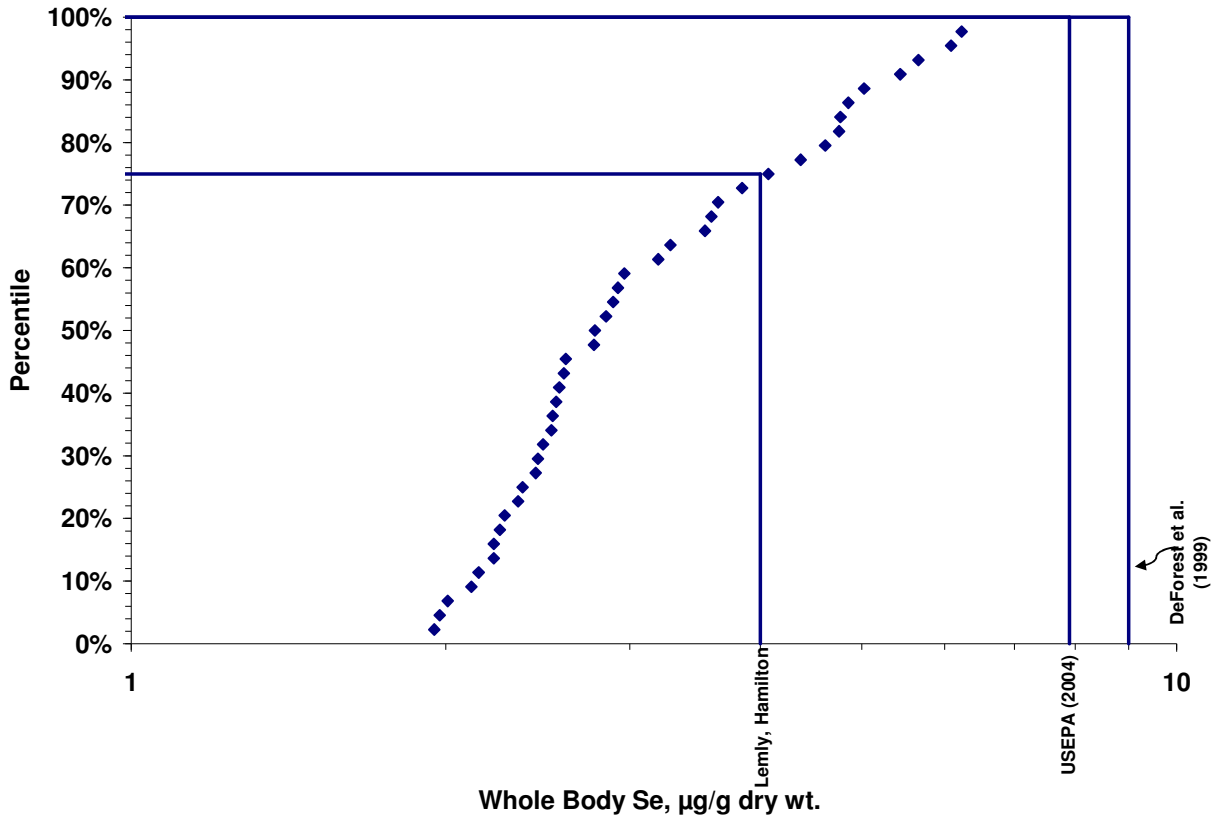


Figure 8. Cumulative distribution of whole body and muscle selenium concentrations in fish from reference sites in northern Saskatchewan. Data from Cameco Corporation (2007).

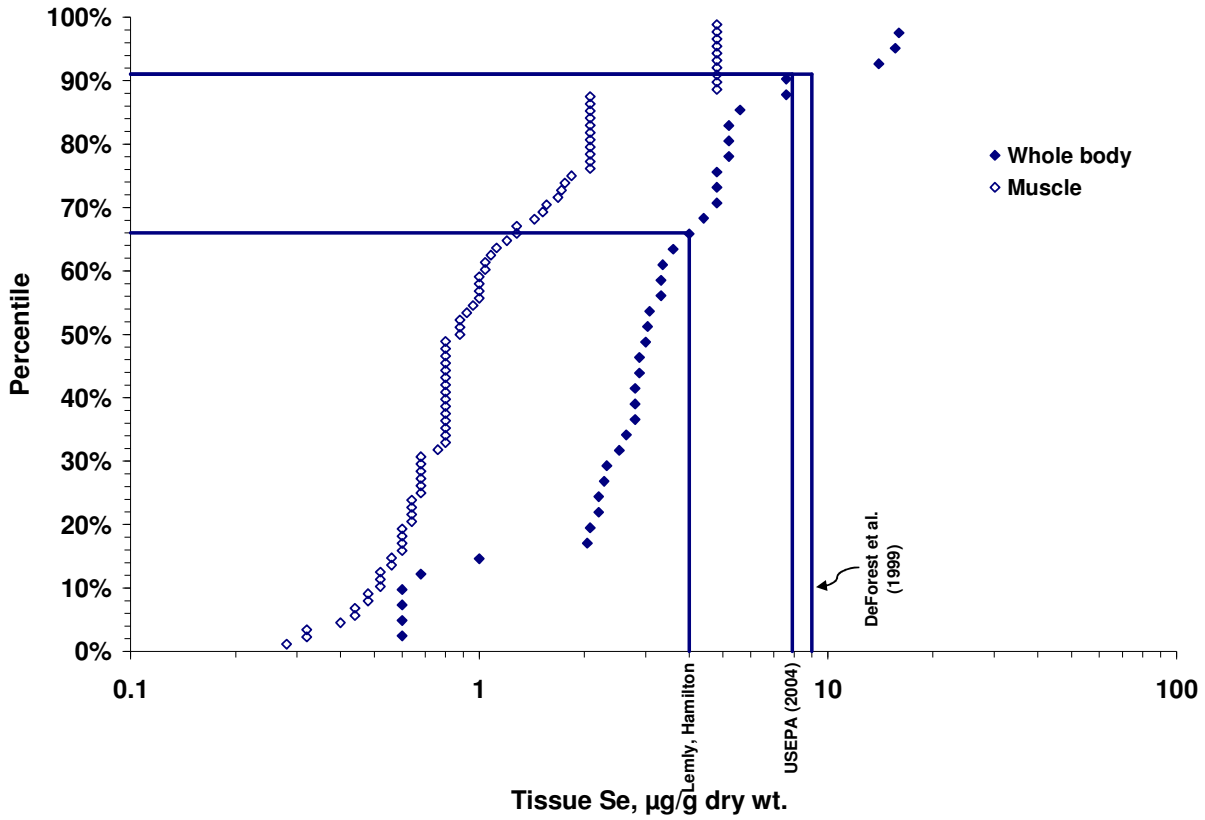


Figure 9. Cumulative distribution of muscle selenium concentrations in fish from reference sites in the north east slopes region of Alberta. Data from Casey and Siwik (2000).

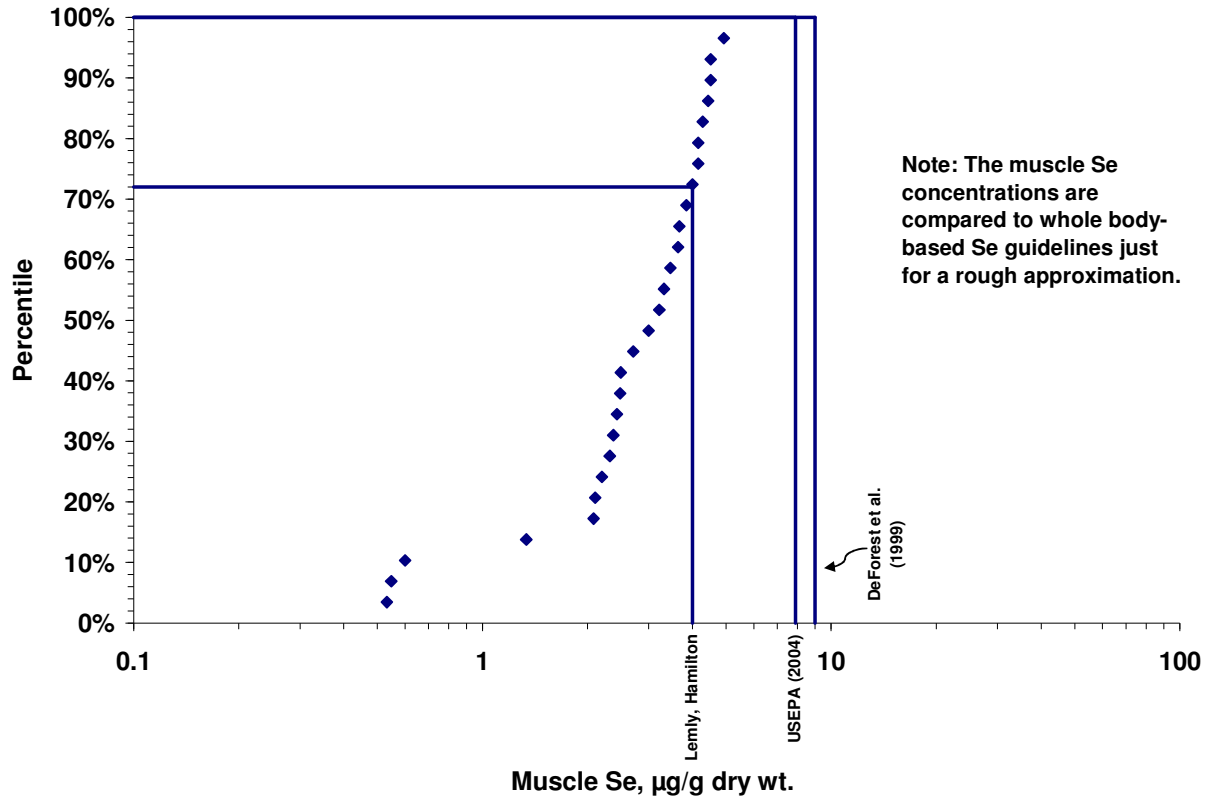


Figure 10. Cumulative distribution of egg selenium concentrations in fish from reference sites in the north east slopes region of Alberta. Data from Casey and Siwik (2000).

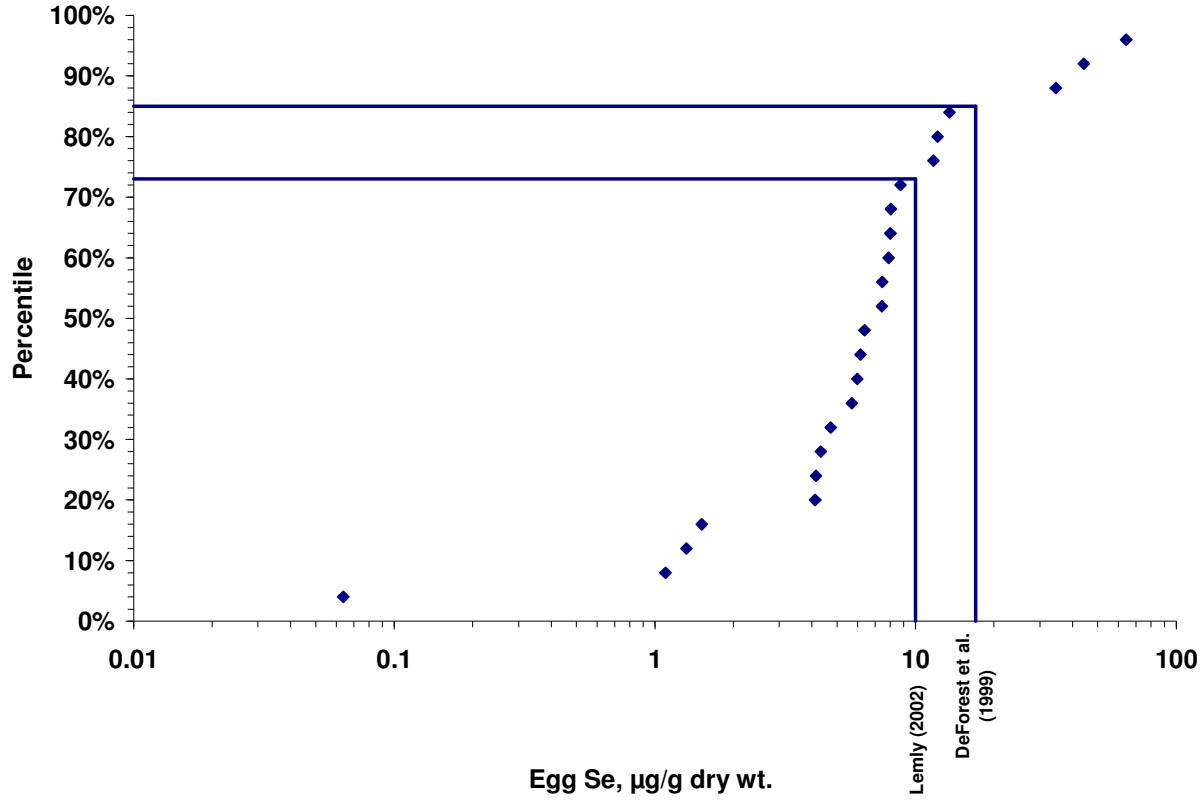


Figure 11. Cumulative distribution of whole body selenium concentrations in fish from reference sites in northern Saskatchewan. Data from Golder Associates (2008).

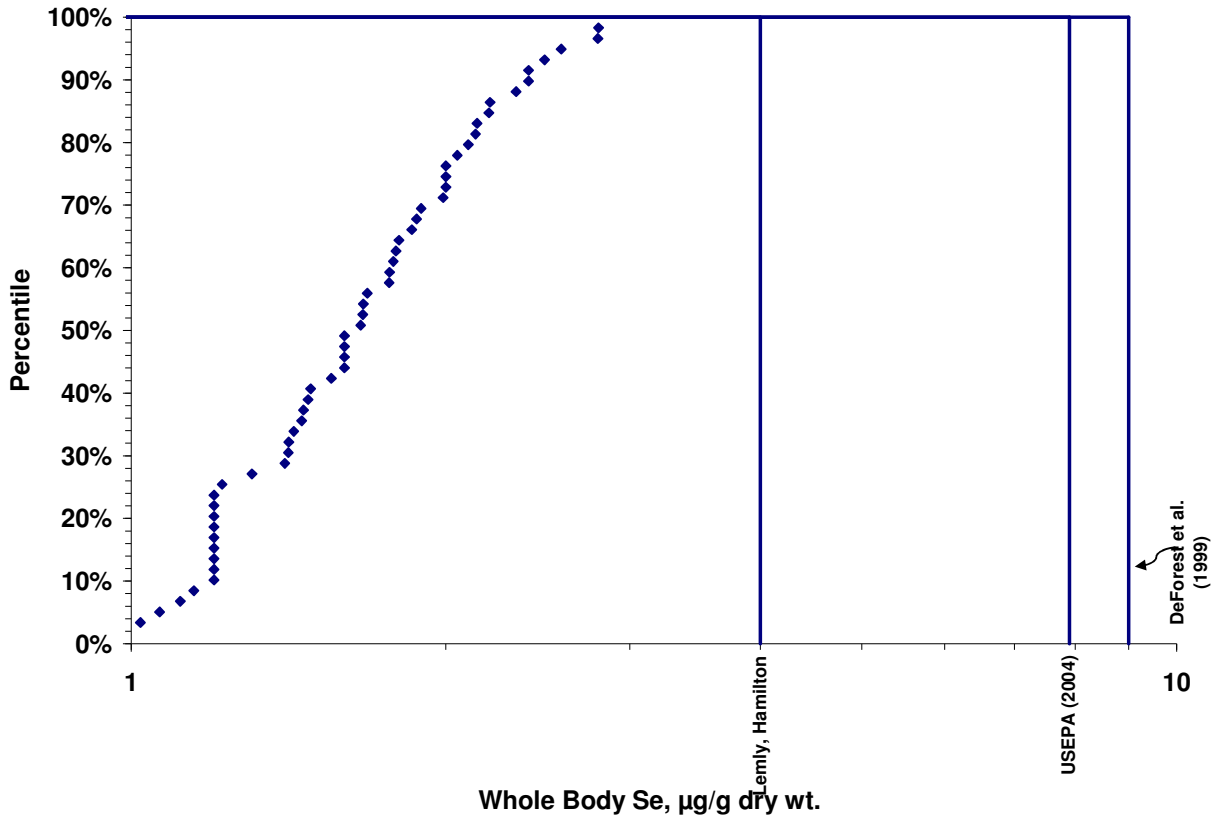


Figure 12. Cumulative distribution of muscle selenium concentrations in fish from reference sites in the north east slopes region of Alberta. Data from Mackay (2006).

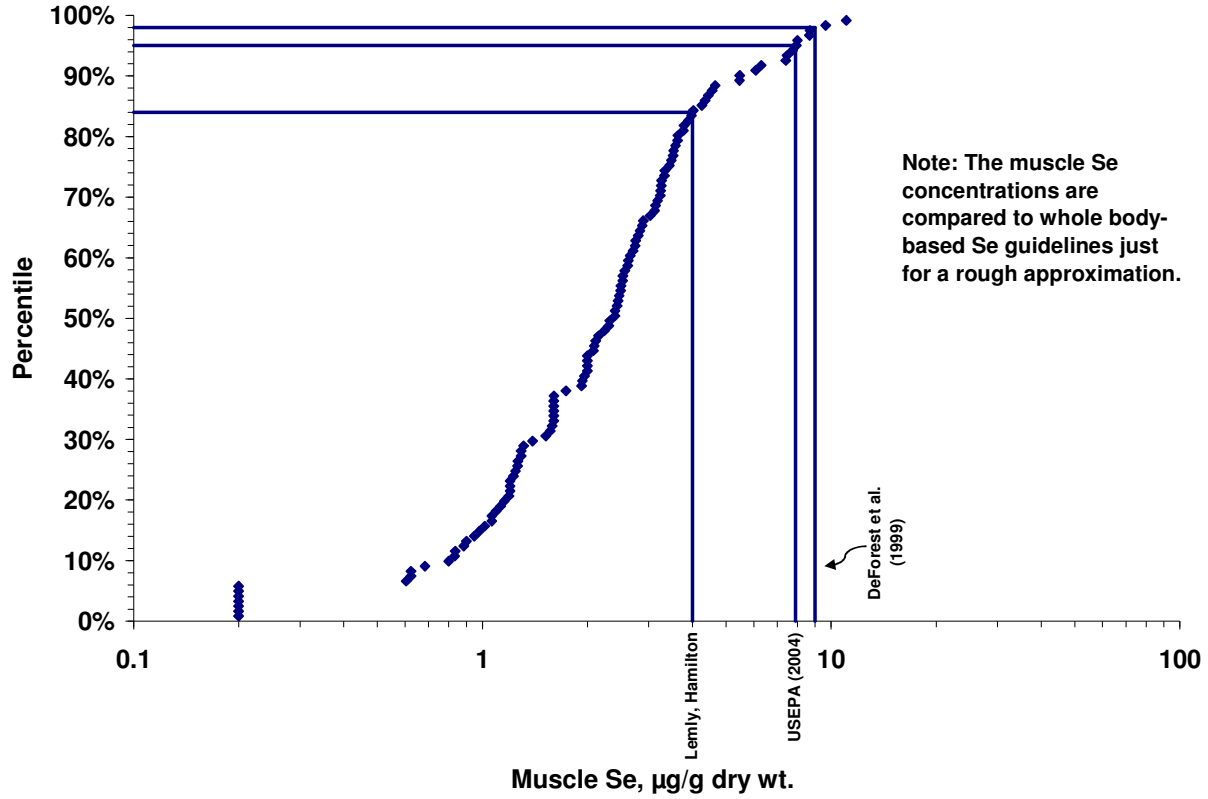


Figure 13. Cumulative distribution of ovary selenium concentrations in fish from reference sites in the north east slopes region of Alberta. Data from Mackay (2006).

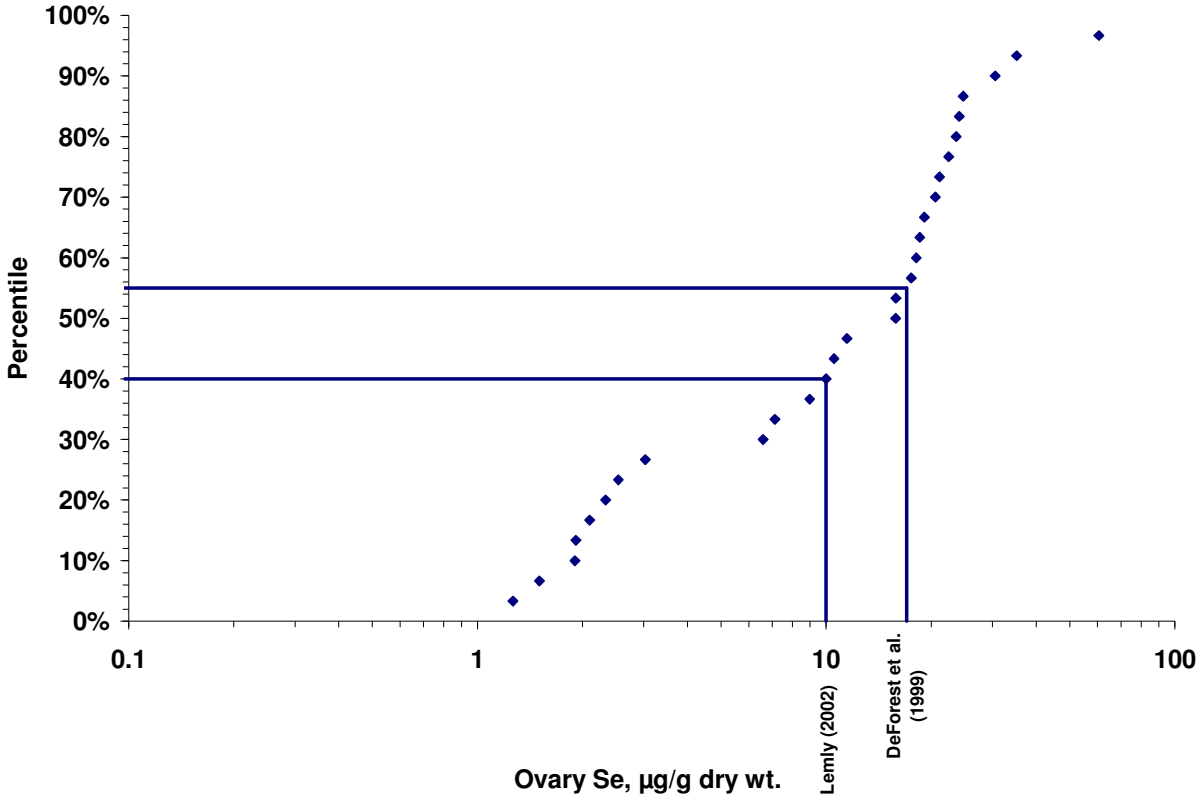


Figure 14. Cumulative distribution of whole body selenium concentrations in fish from all reference sites.

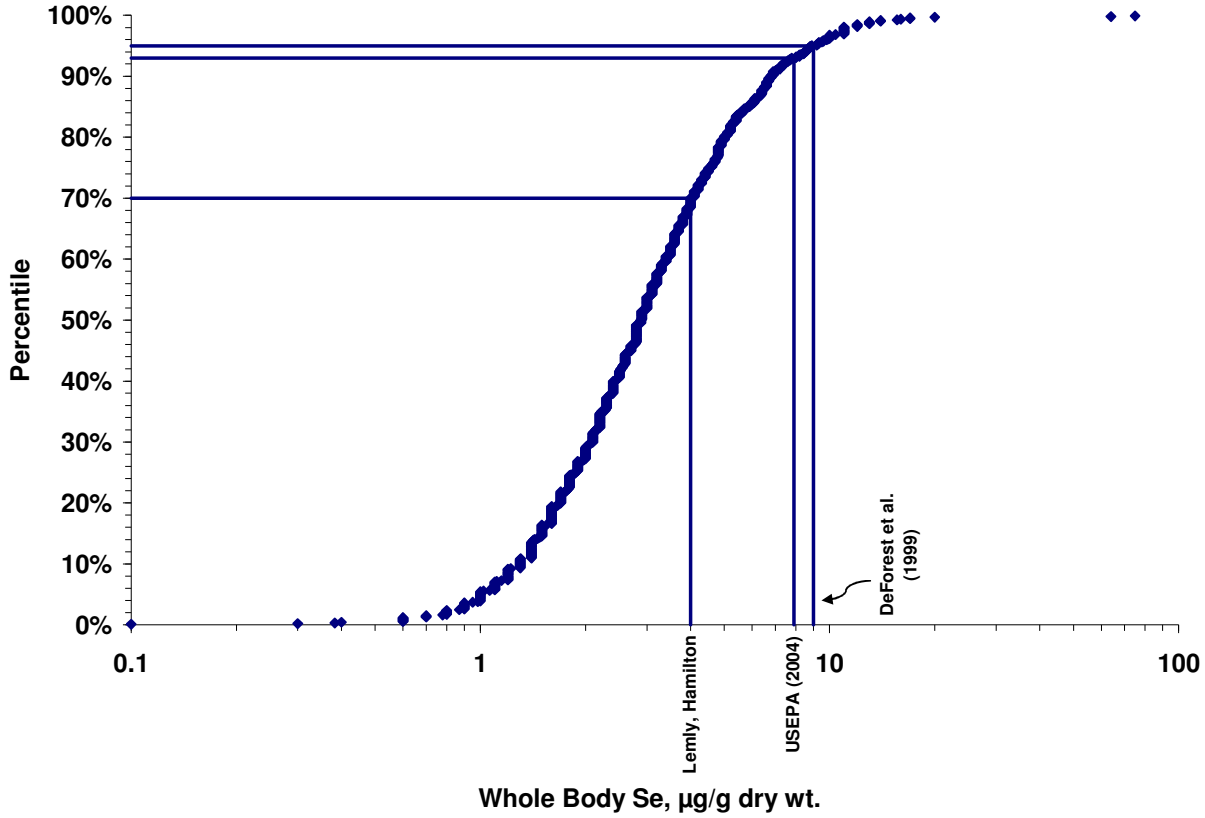


Figure 15. Cumulative distribution of muscle selenium concentrations in fish from all reference sites.

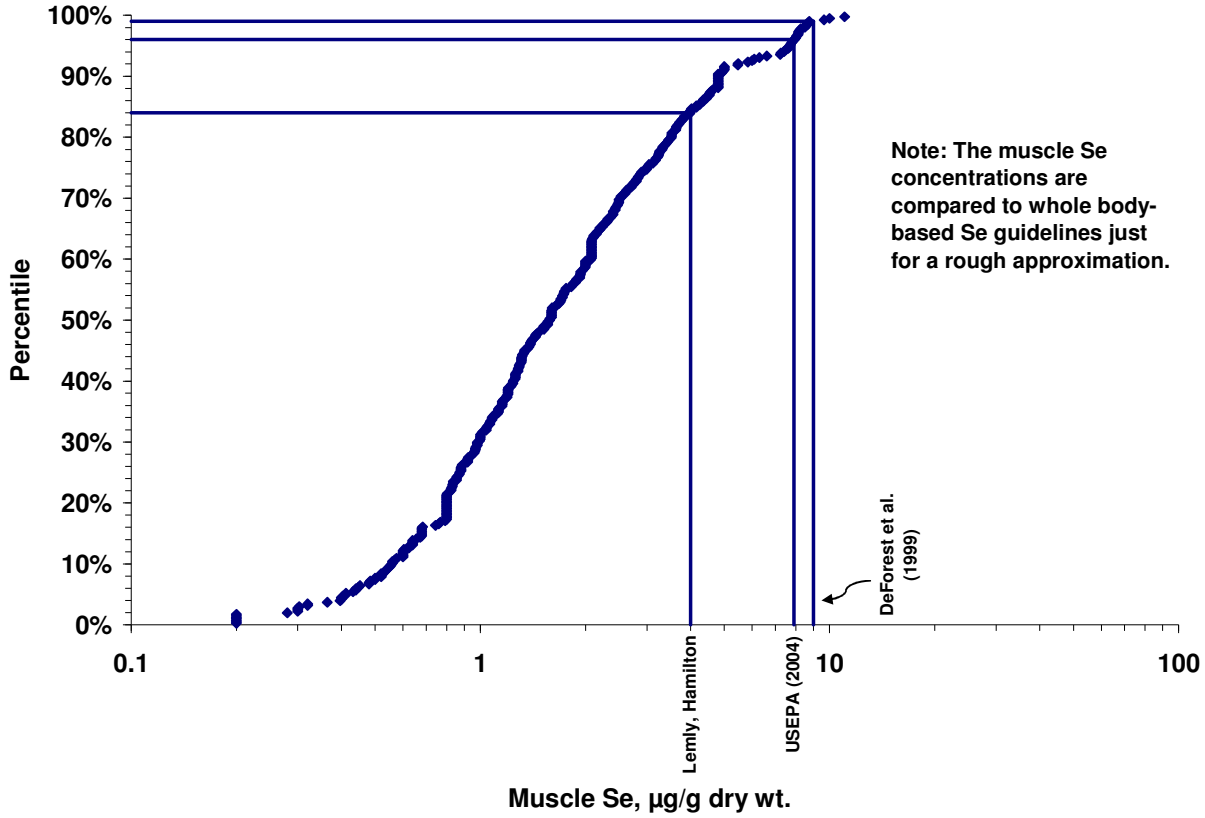


Figure 16. Cumulative distribution of egg selenium concentrations in fish from all reference sites.

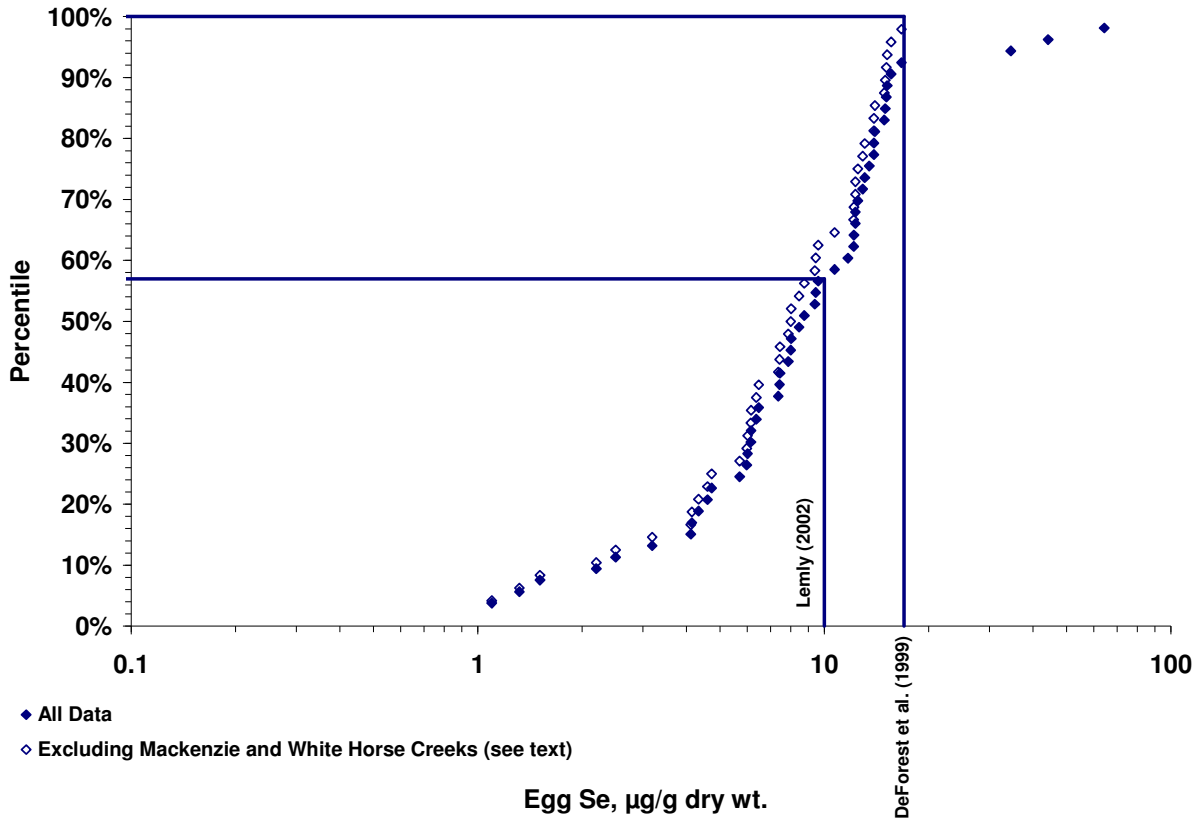
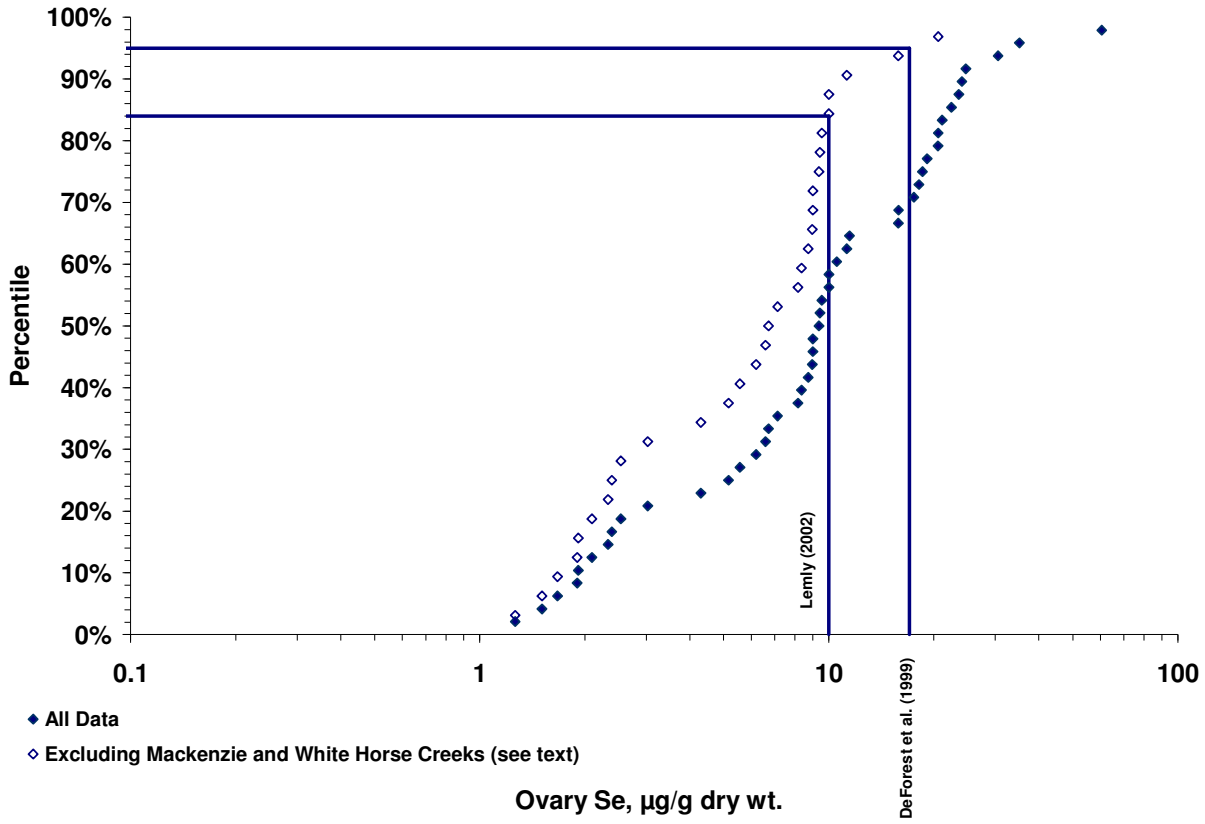


Figure 17. Cumulative distribution of ovary selenium concentrations in fish from all reference sites.



TABLES

Table 1. Measured muscle selenium concentrations and estimated whole body selenium concentrations measured in Mayo Reservoir, North Carolina.

Species	Transect/Station[1]	Mean Muscle Se (µg/g dry wt.)	Mean Estimated Whole Body Se (µg/g dry wt.)[2]
Bluegill	B1	9.3	8.4
	B3	8.0	7.3
	E	6.0	5.7
	G	3.4	3.4
Largemouth bass	B1	11	9.7
	B3	10	8.9
	E	10	8.9
	G	7.8	7.2
Catfish[3]	B1	7.2	6.7
	B3	5.7	5.4
	E	4.0	3.9
	G	2.8	2.8

[1] Transect B extends from the ash pond, with Station B1 being closest to the ash pond and Station B3 being near the far shore away from the ash pond. Transects E and G are approximately 1.75 and 5 miles upstream of the ash pond, respectively.

[2] Whole body Se concentrations were estimated from muscle Se concentrations using Equation I from USEPA (2004).

[3] Catfish comprises white catfish, yellow bullhead, brown bullhead, and flat bullhead.