Selenium Concentrations in Fish Tissue Collected from Reference Water Bodies in the United States and Canada

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Abstract

Large areas of the United States (US) and Canada, particularly in the west, contain seleniferous marine shales. When these shales are exposed to weathering, selenium (Se) may be mobilized to surface waters and bioavailable to aquatic biota. Fish and aquatic-dependent birds, and possibly other oviparous animals (e.g., amphibians), are the most susceptible aquatic organisms to Se toxicity. The bioavailability of Se to aquatic biota is highly dependent on site-specific factors and, accordingly, fish tissue-based criteria and guidelines have been recommended for monitoring and potentially regulating Se levels in surface waters. In general, with the exception of coal-fired power plants, Se toxicity issues are of greatest concern where Se is naturally occurring at high levels and anthropogenic processes are resulting in the mobilization of Se from seleniferous geological formations. The same areas susceptible to increased Se levels from anthropogenic activities are also susceptible to increased Se levels from natural weathering, where seleniferous bedrock or deposits are exposed. Accordingly, the regions where Se criteria are of greatest interest for regulating Se or performing ecological risk assessments may often have elevated Se levels from both anthropogenic and natural processes. The range between the likelihood of Se toxicity and likelihood of no toxicity in these areas, therefore, can be narrow. We compiled reference site fish tissue Se data from the published literature and site-specific monitoring reports for comparison to currently recommended fish tissue-based criteria and guidelines, and evaluated the ability of various Se criteria and guideline values to differentiate between anthropogenically influenced and reference sites. The results of this evaluation of reference site Se data support the premise that the more conservative fish tissue-based Se guidelines are not appropriate for naturally seleniferous regions in the US and Canada.

Study Objectives

- Compare fish tissue-based selenium (Se) guidelines with Se concentrations measured in fish collected from reference water bodies in seleniferous regions of the United States (US) and Canada.
- Compare fish tissue-based Se guidelines with Se concentrations measured in: 1) fish collected from water bodies with population-level impacts linked to Se, and 2) fish eggs or ovaries that were linked to larval effects based on site-specific toxicity studies.

Methods

- Fish tissue-based Se guidelines, based on egg/ovaries and whole body, are summarized in Table 1.
- Sources of reference site fish tissue Se concentration data are summarized in Table 2; study locations are shown in Figure 1.

Table 1. Summary of tissue-based Se guidelines for fish

Tissue	Toxicity Threshold (µg/g dw)	Basis	Source
Published Thresholds Evaluated in this Review			
Eggs/ovaries	10	reproductive failure	Lemly (1996)
	17	EC10 for larval deformities and mortality	DeForest and Adams (in press); DeForest et al. (1999)
Whole body	4	mortality of juveniles and reproductive failure	Lemly (1996); Hamilton (2002)
	8.1	EC10 for larval mortality and edema in offspring of exposed parent fish	DeForest and Adams (in press)
Other Published Thresholds			
Eggs/ovaries	> 16 – 40	range in "effects thresholds" for cold-water species	Chapman (2007)
Whole body	9	EC10 for larval mortality and edema in offspring of exposed parent fish	DeForest et al. (1999)
	7.91	LOAEC for juvenile bluegill simultaneously exposed to Se and simulated winter conditions, with 5.85 µg/g dw considered to be a summer/fall trigger for monitoring in winter; data from Lemly (1993)	EPA (2004)

dw – dry weight
EC10 – concentration that causes a non-lethal effect in 10% of an exposed population
LOAEC – lowest-observed-adverse-effect concentration

Table 2. Sources of fish tissue selenium data from reference water bodies

Coal Mining Regions

Alberta, Canada	*British Columbia, Canada*	*West Virginia, USA*
Casey and Siwik (2000)	Carmichael and Chapman (2006)	WVDEP (2009, 2010)
Holm (2002); Holm et al. (2003; 2005)	Golder Associates (2005)	
Mackay (2006)	Kennedy et al. (2000)	
Mainstream Aquatics (2006, 2009)	McDonald (2009)	
McKeown and Chapman (2005)	McDonald and Strosher (1998)	
	Minnow Environmental and Paine Ledge (2006)	
	Rudolph et al. (2008)	

Phosphate Mining Regions	Uranium Mining Regions	Other Mining/Mineral Regions
Idaho, USA	*Saskatchewan, Canada*	*British Columbia, Canada*
Hamilton et al. (2002)	Paton (2007)	Golder Associates (2009)
Hamilton and Buhl (2003)	Golder Associates (2008)	*Ontario, Canada*
Stenhouse (2008)	Muscatello et al. (2006; 2008)	Dreidger et al. (2009)
NewFields (2005, 2008)	Muscatello and Janz (2009a, b)	*Yukon Territory*
		EDI (2008)

Irrigation Drainage Regions	Oil and Gas Regions
Western USA	*Texas, USA*
Seiler et al. (2003)	GEI Consultants (2007, 2008)

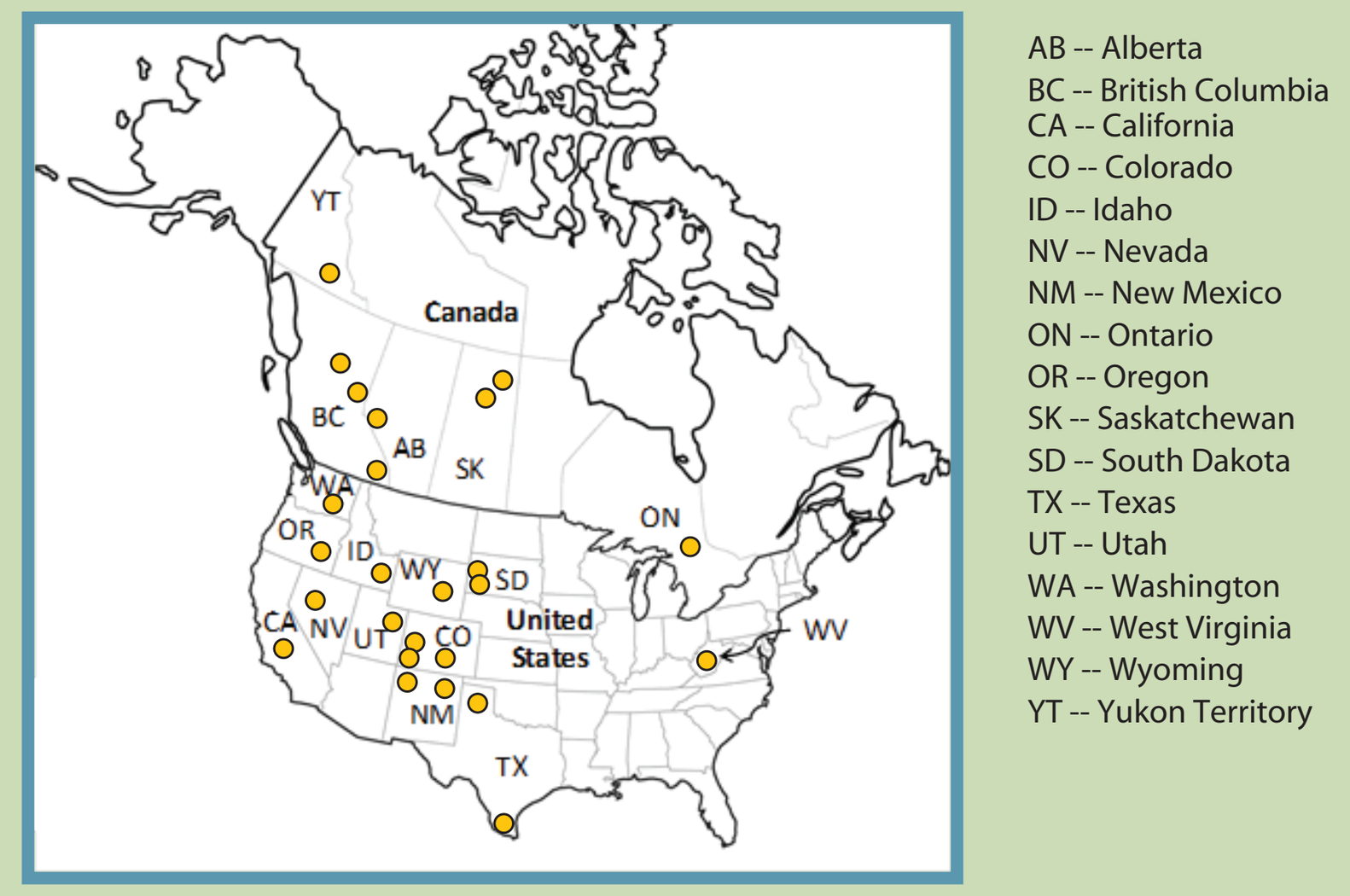
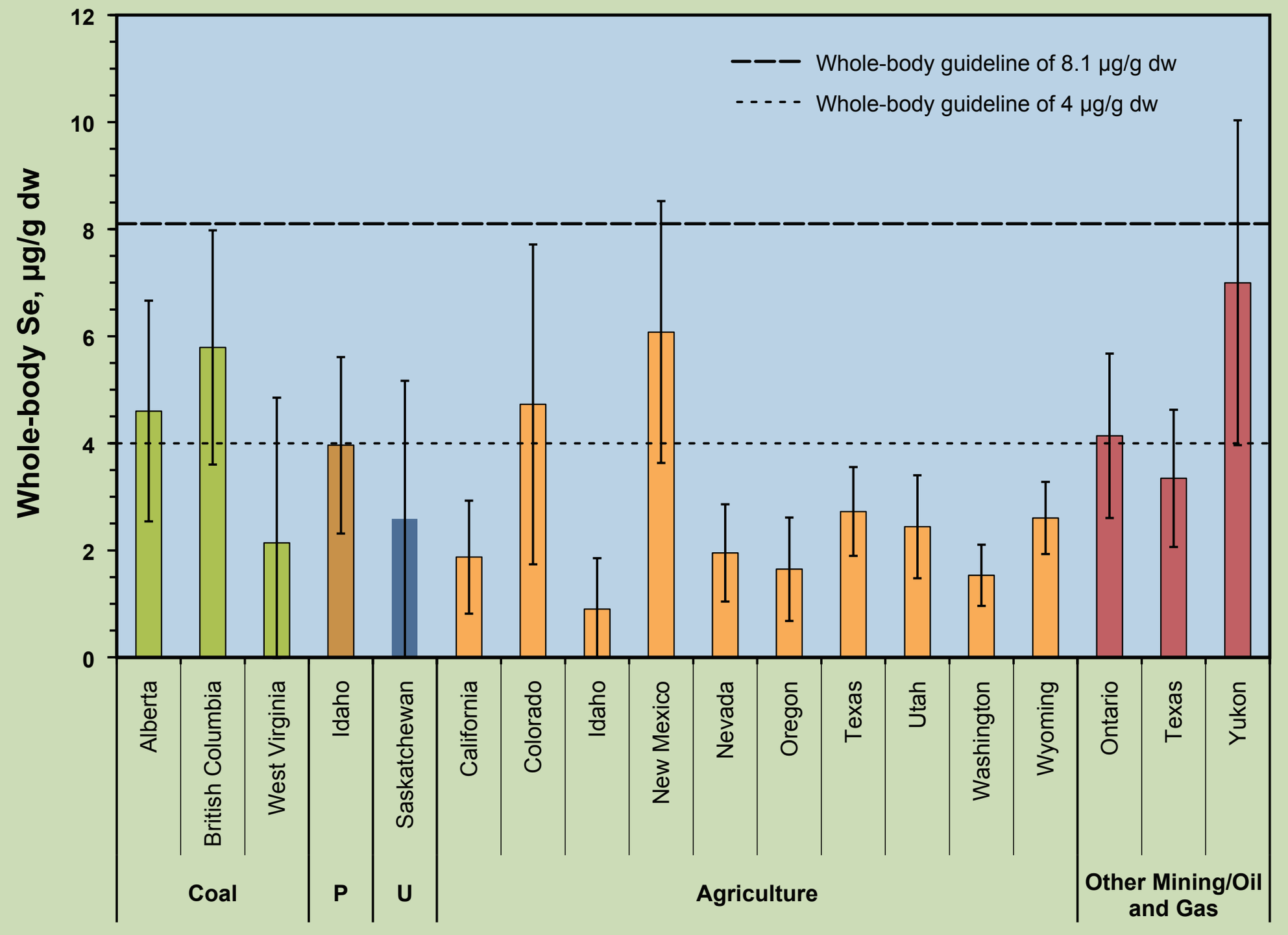


Figure 1. Locations of studies with reference site Se data used in this evaluation

Results

- Mean whole-body reference site Se concentrations never exceeded the whole-body Se guideline of 8.1 µg/g dry weight (dw), but mean Se concentrations exceeded the lower guideline of 4 µg/g dw in 7 of 18 regions (Figure 2).
- Mean egg/ovary reference site Se concentrations never exceeded the egg/ovary Se guideline of 17 µg/g dw, while a lower egg/ovary Se guideline of 10 µg/g dw was exceeded in coal mining regions of British Columbia and nearly equaled in coal mining regions of Alberta (Figure 3).
- The highest whole-body reference site Se concentrations were measured in Alberta, British Columbia; The Yukon Territory; and Idaho.
  - No clear patterns in magnitudes of whole-body Se concentrations in salmonids (e.g., trout, mountain whitefish) emerged, with mean Se concentrations being sometimes less than and sometimes greater than the lower whole-body Se guideline of 4 µg/g dw (Figure 4).
  - Mean whole-body Se concentrations for sculpin species were consistently higher than the guideline of 4 µg/g dw, with means across sites ranging from 4.1 to 7.1 µg/g dw (Figure 4).
- Egg/ovary Se concentrations from Alberta and British Columbia reference sites were variable between species, ranging from 2.6 µg/g dw in a single bull trout sample to 20.6 µg/g dw in a single mountain whitefish sample (Figure 5).
- Mean egg/ovary Se concentrations for mountain whitefish and cutthroat trout were higher than the egg/ovary Se guideline of 10 µg/g dw, with some individual egg/ovary Se concentrations for brook trout, rainbow trout, and longnose sucker also exceeding 10 µg/g dw (Figure 5). It appears that cutthroat trout and mountain whitefish may have a propensity to bioaccumulate higher Se concentrations in the ovaries and eggs as compared with other species sampled to date.



Note: P = phosphate mining region, U = uranium mining region

Figure 2. Mean (±SD) whole-body Se concentrations in reference site fish collected from various mining regions in the US and Canada

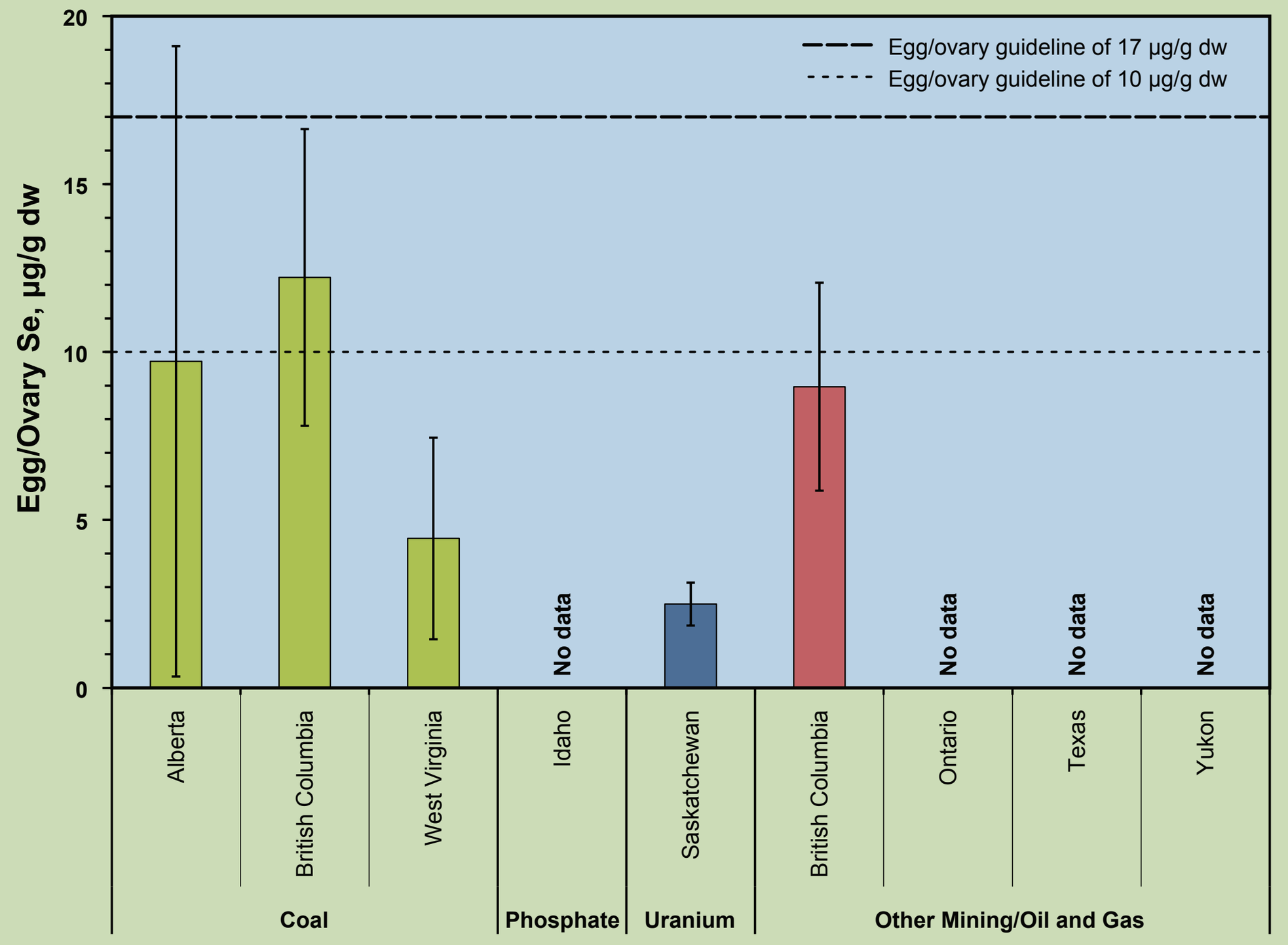


Figure 3. Mean (±SD) egg/ovary Se concentrations in reference site fish collected from various mining regions in the US and Canada

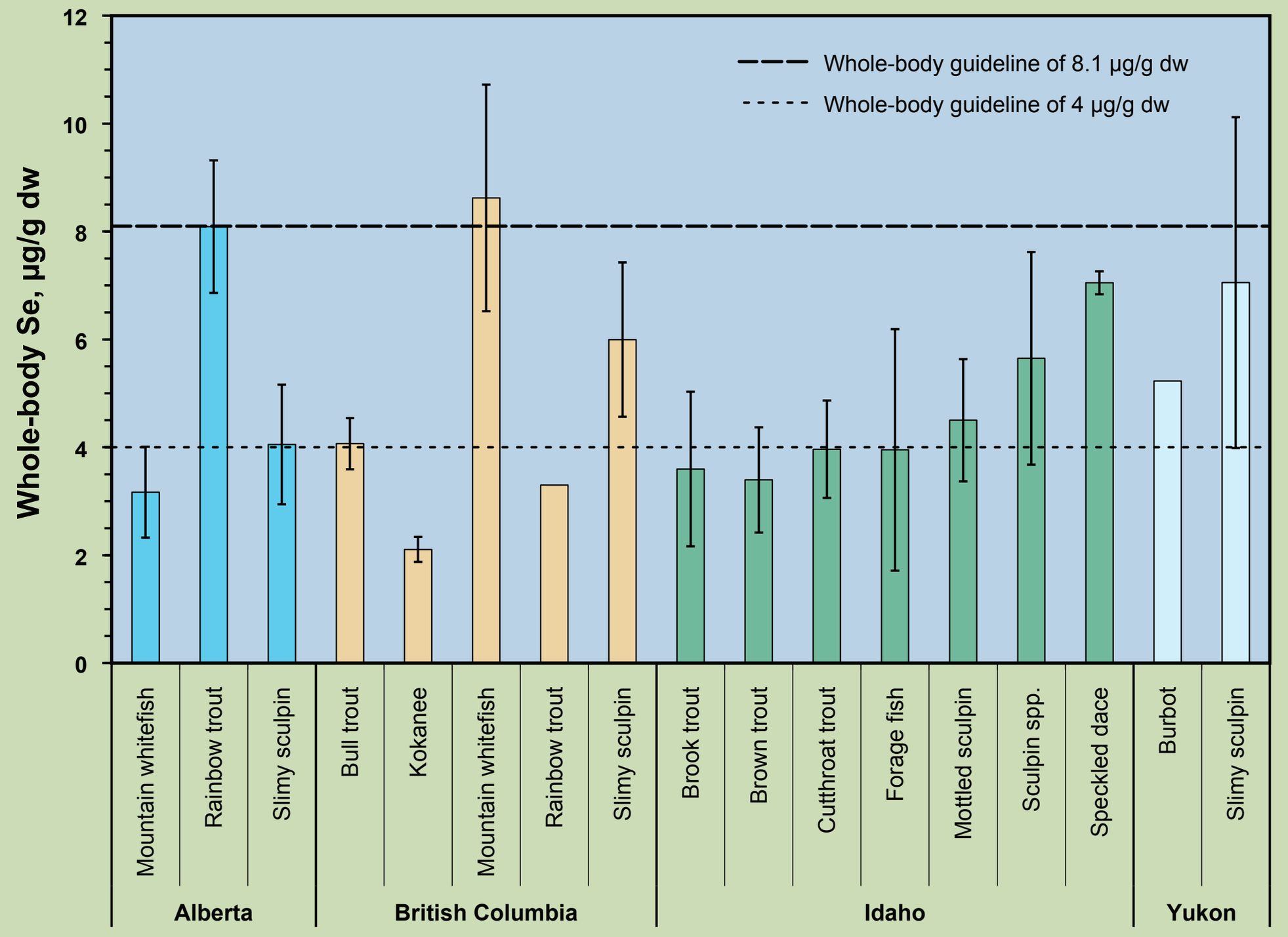


Figure 4. Inter-species comparison of mean (±SD) whole-body Se concentrations in reference site fish collected from various locations

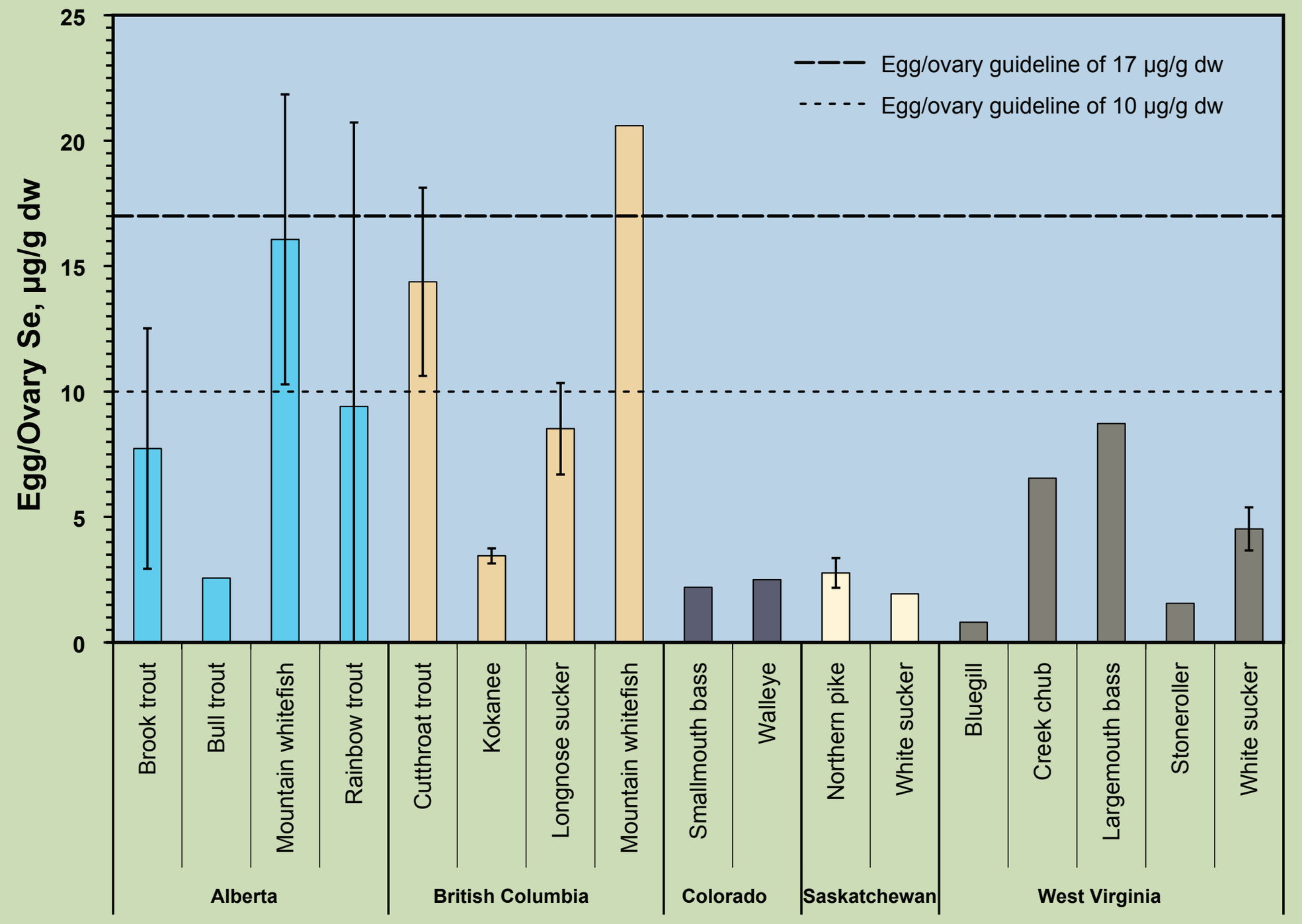


Figure 5. Inter-species comparison of mean (±SD) egg/ovary Se concentrations in reference site fish collected from various locations

Discussion

Uncertainties

- Certain species, such as various trout species and mountain whitefish, have large home ranges and may move between Se exposure sites and reference sites; however, sculpin have a small home range (mean whole-body Se concentrations in sculpin collected from Alberta, British Columbia; YukonTerritory; and Idaho reference sites always exceeded the lower whole-body Se guideline of 4 µg/g dw).

Field-Based Selenium Bioaccumulation and Effects Data

- In addition to reference site fish tissue Se concentrations, fish tissue Se guidelines were also compared with:
  - Sites where population-level Se impacts were observed
  - Sites with moderately elevated Se concentrations and no evidence of population-level impacts
  - Site-specific toxicity data at locations where individual-level larval effects were evaluated
- The lower whole-body Se guideline of 4 µg/g dw was exceeded by mean whole-body Se concentrations at sites that had no indication of population-level impacts or sites where Se concentrations had recovered, while the higher whole-body Se guideline of 8.1 µg/g dw was not exceeded, or only slightly exceeded, at the same locations (Figure 6).
- The lower egg/ovary Se guideline of 10 µg/g dw was exceeded by mean egg/ovary Se concentrations at sites where there was no indication of effects, while the higher egg/ovary Se guideline of 17 µg/g dw was only exceeded at sites where individual- or population-level effects were observed (Figure 7).

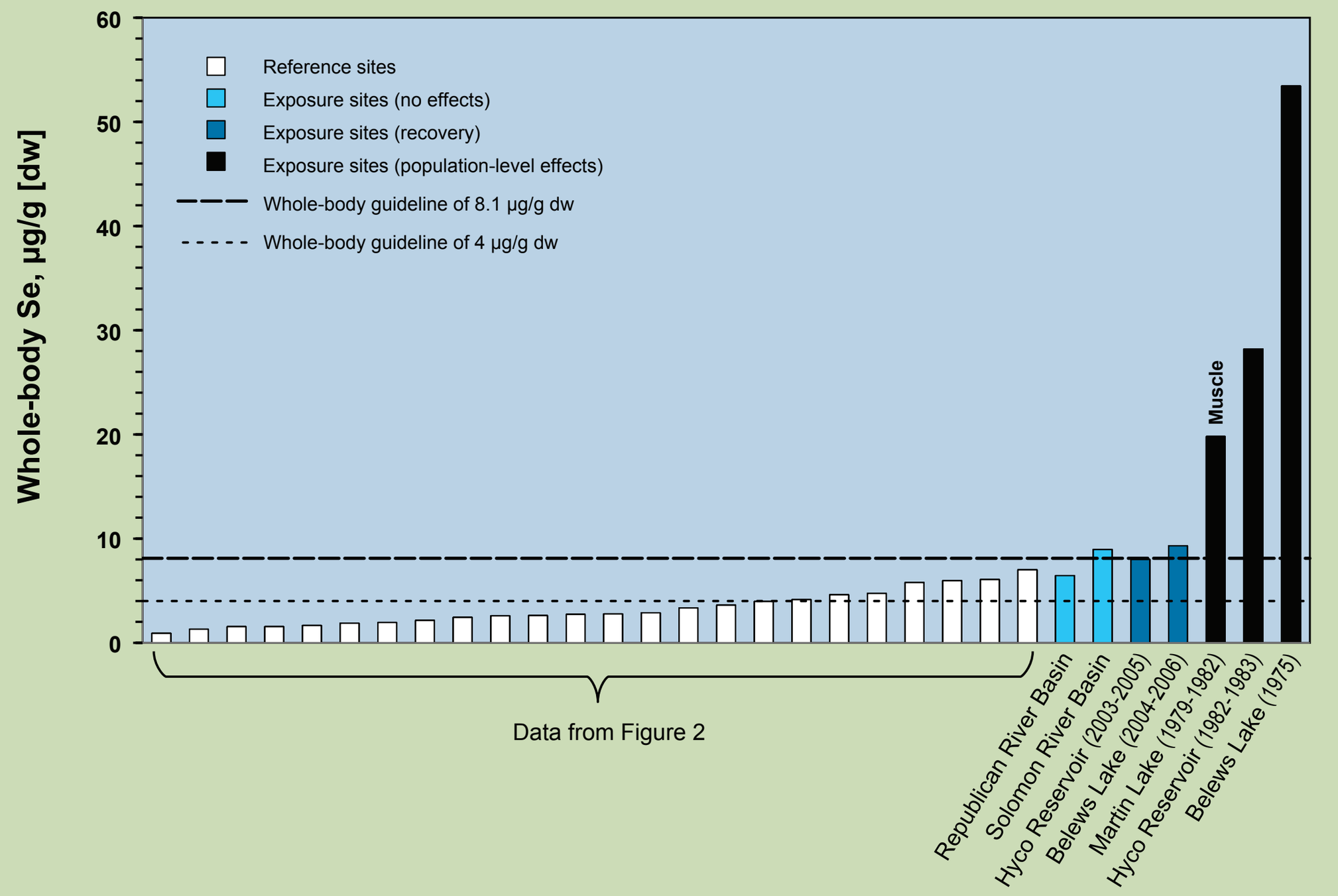
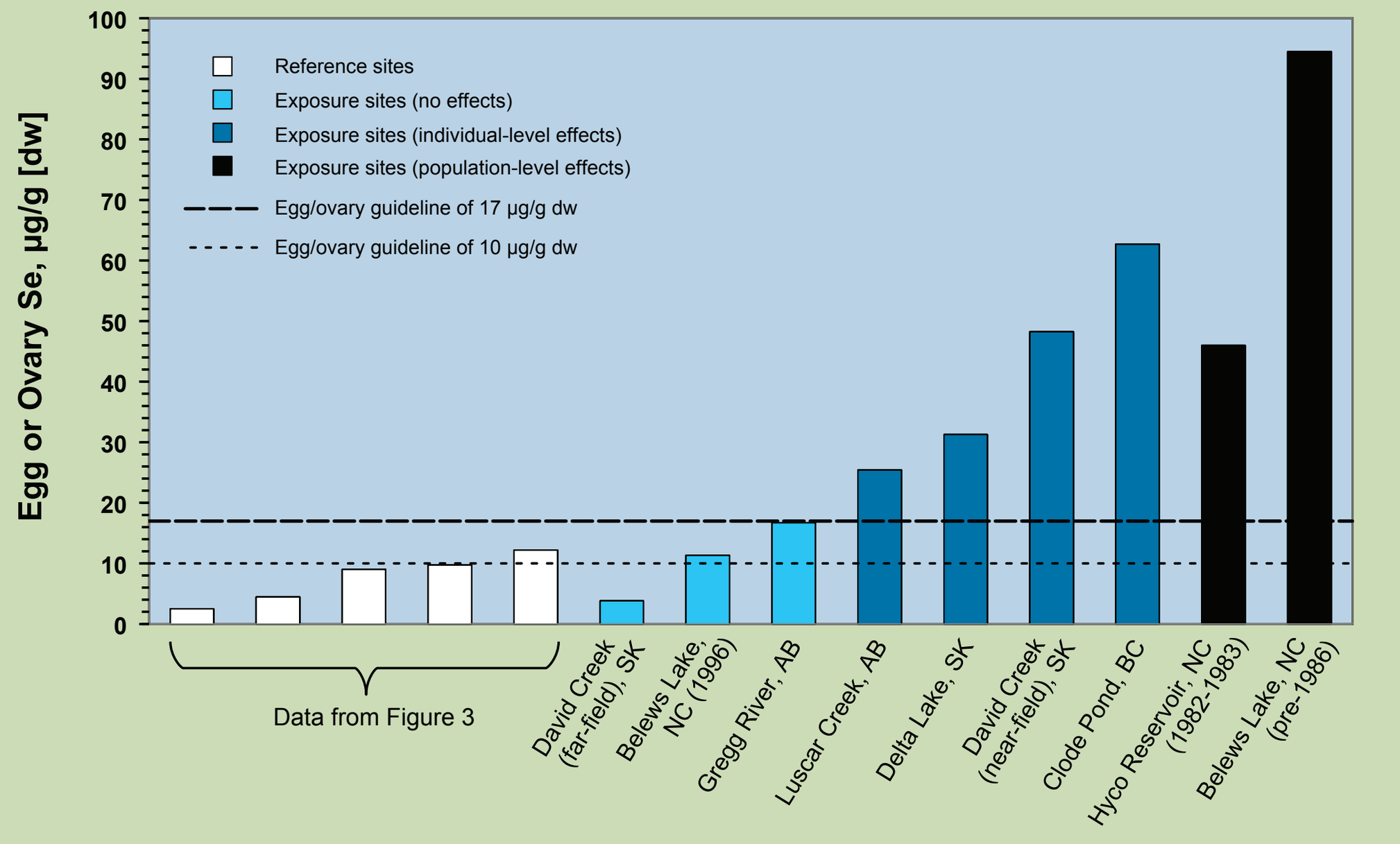


Figure 6. Comparison of whole-body Se guidelines with whole-body selenium concentrations in fish collected from reference sites, exposure sites with no evidence of effects, exposure sites with recovery from selenium-related effects, and exposure sites associated with population-level effects



Source: Exposure site data from Gillespie and Baumann (1986), Holm et al. (2005), Lemly (1997), Muscatello et al. (2006), and Rudolph et al. (2008).
Note: Individual-level effects were operationally defined as greater than a 10% mean effect relative to the corresponding reference site.

Figure 7. Comparison of egg/ovary Se guidelines with egg/ovary selenium concentrations in fish collected from reference sites, exposure sites with no evidence of effects, exposure sites associated with individual-level effects, and exposure sites associated with population-level effects

Summary and Conclusions

- Se concentrations in fish tissues are naturally elevated at certain reference sites in seleniferous regions of the US and Canada.
- The whole-body and egg/ovary Se guidelines of 8.1 and 17 µg/g dw, respectively, are rarely exceeded; however, it is not unusual for reference site Se concentrations to exceed the lower whole-body and egg/ovary Se guidelines of 4 and 10 µg/g dw, respectively.
- Both the whole-body and egg/ovary Se guidelines of 8.1 and 17 µg/g dw, respectively, nicely distinguish the reference and no-effect sites from the effect sites, whereas the whole-body and egg/ovary Se guidelines of 4 and 10 µg/g dw, respectively, are equaled or exceeded in some reference site regions, as well as in water bodies that had either recovered or in which site-specific toxicity was not observed.

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