Chapter 3. Selenium Levels of Biota from Retired Agricultural Lands in the San Joaquin Valley, California

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3.1. Introduction

The high concentrations of selenium in the groundwater and soils of the Land Retirement Demonstration Project (LRDP) study sites have the potential to be detrimental to wildlife. Alkaline soils and high selenium levels, conditions that are present on retired lands, are favorable to selenium bio-availability (USDI 1998). High concentrations of selenium are known to cause a variety of adverse effects to wildlife including embryonic malformation and death, reduced longevity, reduced reproductive success, reduced growth and survival rates, winter stress syndrome, food aversion, anemia and mass wasting, alopecia (loss of feathers) and loss of hair and nails, depressed immune system function, altered enzyme function, skin lesions, respiratory failure, and paralysis (Ghosh et al. 1993, Hedland 1993, Heinz and Fitzgerald 1993, Johnston 1987, Koller and Exon 1986, Lemly 1993a and b, Ohlendorf et al. 1993, Saiki and Ogle 1995). Although the groundwater and soils in the region contain high amounts of selenium, the degree that selenium is available to and accumulates in biota from agricultural lands and upland habitats is not well understood. The effects of land retirement and of habitat restoration of retired lands on the bio-availability of selenium are not known.

We monitored selenium levels in plants, invertebrates, and small mammals collected from retired agricultural lands over a 5-year period at the Tranquillity study site and over a 3-year period at the Atwell Island study site (see Figure 1-1 for site locations) following protocols established by the project's Biological Opinion (FWS 1999). Table 3-1 provides a list of the biotic groups monitored, the corresponding population-level performance standard established by FWS (1999) for each group, and an indication whether performance standards were met.

Results are compared to selenium levels found in similar biotic groups collected from selenium-normal situations in the western United States (USDI 1998). We also compare our results to the concentrations of selenium in corresponding biota that were previously collected from Kesterson National Wildlife Refuge (Kesterson NWR, see Figure 1-1), a site where high levels of selenium resulting from the deposition of agricultural drain water caused a variety of toxic effects to wildlife (USDI 1992). When comparative data are not available from Kesterson NWR, Reclamation relates its findings to other local and regional information.

Table 3-1. List of biotic groups monitored, corresponding performance standards (USFWS 1999), and an indication whether performance standards were met. ATWL = Atwell Island site, TRNQ = Tranquillity site. All selenium values are on a dry weight basis except rodent blood and coyote or kit fox blood, which is on a wet weight basis.

Biotic group	Performance standard	Met	Not met	Not monitored
Vegetation	Not to exceed 2ppm (2 mg/kg) Se	X		
Invertebrates	Not to exceed 2.5ppm (2.5 mg/kg) Se			
Crickets		X		
Beetles		X		
Spiders		X		
Isopods		X (ATWL)	X[1] (TRNQ)	
Reptiles				
Whole body	Not to exceed 3ppm (3mg/kg) Se			X[2]
Feces	Not to exceed 2ppm (2mg/kg) Se			X[2]
Eggs/ovaries	Not to exceed 5ppm (5 mg/kg) Se			X[2]
Blood	Not to exceed 1 ppm (1 mg/kg) Se			X[2]
Birds				
Blood	Not to exceed 1 ppm (1 mg/kg) Se			X[3]
Eggs	Not to exceed 5ppm (5 mg/kg) Se			X[3]
Feathers	Not to exceed 4ppm (4 mg/kg) Se			X[3]
Rodents				
Hair	Not to exceed 5ppm (5 mg/kg) Se	X[4]		
Blood	Not to exceed 0.5ppm (0.5 mg/kg) Se	X[4]		
Coyote or kit fox blood	Not to exceed 1 ppm (1 mg/kg) Se			X[5]

X[1] – Isopods from TRNQ slightly exceeded the performance standard for invertebrates. This is not unexpected since Isopods are known to be detritus feeders and accumulate Se in greater quantities than other invertebrate groups.
X[2] – Se levels in reptiles were not monitored because they were not available for sampling (see Chapter 4).
X[3] – Monitoring of birds was only required if standing water was present for more than 30 days. Standing water did not occur on either site.
X[4] – Although performance standards were set for rodent hair and blood, it was cooperatively determined that it would be preferable to sample rodent bodies and livers. No subsequent performance standards were established for rodent bodies and livers, but the Se values obtained for rodent bodies and livers appear to meet performance objectives.
X[5] – Se levels in coyote or kit fox were not monitored because they were not available for sampling.

3.2. Methods

The monitoring of selenium concentrations in groundwater (see Chapter 2) and biota followed a tiered sampling approach that was cooperatively developed with the FWS specifically for this project (FWS 1999). The monitoring of selenium in soils (see Chapter 2) was not included in those protocols. The intensity of sampling was based upon the depth to groundwater and concentration of selenium in groundwater. Although the depth to groundwater under the retired lands increased after irrigation ceased (see Chapter 2), the level of monitoring remained at the highest intensity (Tier IV) because of the high selenium concentration present in the groundwater.

At Tranquillity, samples of vegetative and reproductive parts of plants were collected in July and October 1999, June 2000, May 2001, April and May 2002, and in April, May, June, and August 2003. At Atwell Island, plant samples were collected in April and May 2000, May 2001, and April and May 2002. Samples were collected from areas that were widely scattered over the project sites and from a variety of cultivated, uncultivated, and experimental areas when possible. Cultivated areas are those where barley or some other irrigated crop was present; uncultivated areas are those that were fallowed or idled and have not recently received irrigation water. Experimental areas are those where restoration treatments (contouring, planting of native seed, or no treatment) were applied.

We collected samples of native and non-native vegetation that were dominant on the landscape. Hence, the number of species and number of samples collected varied from year to year depending upon the distribution and abundance of each species and the availability of funding (e.g., when sampling at both Atwell Island and Tranquillity concurrently, fewer samples were taken at Tranquillity because of the need to support work at Atwell Island). Despite the yearly changes in vegetation dominance and the variability in sampling, we attempted to collect a standardized set of samples that included a suite of species that were expected to occur in each of the collection areas throughout the study period. Some of these species are *Sisymbrium irio, Brassica nigra, Atriplex argentea, Hordeum murinum, Melilotus indica,* and *Hordeum vulgare*.

The plants were collected when green and not showing signs of advanced water stress. Samples were placed in plastic bags, labeled, and stored on ice. Upon returning to the lab, the samples were washed, dried, separated into “part” (e.g., fruits, vegetative structures, etc.), transferred to a whirl-pack bag, and frozen.

Invertebrate samples consisting of crickets, spiders, isopods, and beetles were collected from Tranquillity in July 1999, June 2000 and 2001, and May 2002 and 2003. At Atwell Island, samples were collected in July 2000, June 2001, and May 2002. Invertebrates were collected from pitfall traps located within the experimental areas of the project sites. At Tranquillity, invertebrates were collected from five pitfall arrays on each of 20, 4 ha (10 ac) study plots. Each pitfall array consisted of four, 13 liter (3 gal) pitfall buckets connected by a 6.1 m

(20 ft) long by 30 cm (1 ft) high galvanized steel flashing. One composite sample of each invertebrate type was collected from each study block (a set of four plots, one of each restoration treatment configured in a randomized block design). At Atwell Island, one composite sample of each invertebrate type was collected from each of three study areas. Each study area consisted of 16, 0.8 ha (2 ac) plots with each plot containing a single pitfall array. We attempted to collect a composite sample of at least 2 grams (g) of each invertebrate type from a pitfall bucket, pitfall array, multiple arrays on a plot, or sometimes multiple plots within a study block or study area. The spatial distribution of each sample depended upon the abundance and availability of the invertebrate type being collected. All samples were individually bagged and labeled, immediately stored on ice, then transferred to a freezer upon returning to the lab.

Small mammals were collected from the two project sites by a combination of live-trapping using Sherman traps and by collecting mammals from pitfall traps. We attempted to collect five deer mice *(Peromyscus maniculatus)* from each landform (cultivated, uncultivated, and experimental) and five shrews *(Sorex ornatus)* from experimental areas. Trapped animals were sacrificed by cervical dislocation, individually bagged and labeled, and placed on ice. Once the samples arrived at the lab, the livers were extracted from the animals and all samples were frozen. Small mammal liver tissues were analyzed for selenium concentration separately from the remaining body tissues. Small mammal body and liver tissues were collected and analyzed, instead of hair and blood, to ensure that an adequate amount of tissue for analysis could be collected.

All biotic samples were analyzed to determine selenium concentrations by Laboratory and Environmental Testing (L.E.T.), Inc., Columbia, Missouri. Data provided include selenium concentration by dry weight, selenium concentration by wet weight, sample dry weight, sample percent moisture, and sample detection limit. The laboratory also provided reports on duplicates, spikes, and reference samples for quality control. Selenium concentration by dry weight was used for analysis. The reported selenium concentrations of some samples were adjusted upwards: when the amount of selenium in a sample was less than the detection limit (e.g., selenium was at non-detectable levels), then the selenium value for that sample was increased to the detection limit. These increases are slight because the detection limits are at the lower range of the data sets. This allows each sample to be included in the analyses and it ensures that the mean selenium concentration for a sample group is not underestimated. The number of non-detects in each sample group is reported in figures and tables so that the bias introduced by this manipulation and the corresponding analysis can be appropriately interpreted.

Selenium data of the biotic samples were log transformed and statistically analyzed by performing single factor (e.g., years) or multifactor (e.g., years and landform types) analysis of variances (ANOVAs) using Statistica 6 (StatSoft, Inc. 2002). In most cases, post-hoc analyses were performed using the Fisher's PLSD test. Student's t-tests were used to compare mean selenium concentrations between the two study sites. SigmaPlot 8.0 (SPSS, Inc. 2002) was used for graphics generation. The geometric mean (hereinafter also referred to as mean) and standard deviation factor of each data group are presented in the data tables. The standard deviation factor is the standard deviation of the log-transformed data that has been back-transformed. The geometric mean and error bars (the geometric mean multiplied by and divided by one standard deviation factor) are shown in the figures. Data points that had selenium levels that exceeded the population-level performance standards are plotted on the figures to show the distribution of the highest and most problematic values within each data set. When a performance standard was not established (e.g., small mammal livers), then those values that exceeded the geometric mean multiplied by one standard deviation factor were plotted.

In addition to comparing mean selenium concentrations to the performance standards established for this project, the team also compared the values to typical population-level background concentrations of selenium in the western United States (USDI 1998) and to selenium concentrations reported in biota from Kesterson NWR (USDI 1992). Kesterson NWR is a site where drainage water was deposited, adverse affects to wildlife occurred, and remedial actions were implemented. Selenium values collected from 1988 to 1992 in the grassland habitat at Kesterson NWR were used because the grassland habitat type most closely resembles the conditions present at the project sites. Whenever comparative data from Kesterson NWR does not exist, Reclamation data are compared to other local and regional information when possible.

3.3. Results

3.3.1. Plants

The mean selenium concentration in 31 species of plants collected from Tranquillity varied from 0.11 to 1.10 mg/kg (Table 3-2). Many of these species are represented by only a single composite sample; hence, they have minor statistical value. Of the 14 species where 5 or more samples were obtained, the mean selenium concentrations were from 0.21 (*Bromus madritensis*) to 0.93 (*Suaeda moquinii*) mg/kg. The mean selenium concentration in 20 species collected from Atwell Island varied from less than 0.17 to 0.5 mg/kg. Ten species from Atwell Island were represented with five or more samples. These varied in selenium from less than 0.17 (*Hemizonia pungens*) to less than 0.25 (*Distichlis spicata*) mg/kg (Table 3-3). Seven species were common to both sites and were represented by five or more composite samples (*A. argentea, B. madritensis, B. nigra, H. murinum, H. vulgare, M. indica, and S. irio*). All of these species were lower in selenium levels at Atwell Island than at Tranquillity ($p < 0.01$ in all cases), except *B. madritensis* ($p = 0.71$).

Twelve species at Tranquillity and 8 species at Atwell Island were collected over multiple years (Tables 3-4 and 3-5). Only one species from Tranquillity, *B. nigra*, clearly showed a temporal increase in selenium; the mean selenium level was greater in 2003 (0.74 mg/kg) than in 2000 (0.47 mg/kg) and 2001 (0.30 mg/kg). There also is some evidence of a temporal increase in selenium in *Avena sp. and A. argentea* at Tranquillity. The mean concentration of selenium in plants from Atwell Island contained at least 32 to 49 percent less selenium than corresponding plant species from Tranquillity during the 3 years of concurrent sampling ($p < 0.01$ each year).

The mean selenium concentrations in plants at both sites were below the performance standards set for the project by the FWS (2.0 mg/kg). No plant samples of any species were collected from Atwell Island exceeded the performance standard; however, 11 samples (3.4%) of 5 species collected from Tranquillity exceeded the performance standard (Table 3-6). Although the mean selenium concentrations in vegetation collected from both Atwell Island and Tranquillity were approximately an order of magnitude less than the mean selenium concentration in plants collected from Kesterson NWR from 1988 to 1992 (2.3 to 6.7 mg/kg), 10 samples collected from Tranquillity were within this range (Table 3-6). The mean selenium concentrations in plants collected from both Tranquillity and Atwell Island are within the range typically found on non-seleniferous soils in the western United States.

Table 3-2. Geometric means (Mean), sample size (N), number of non-detects (ND), minimum (Min), maximum (Max), and standard deviation factor (SD factor) of selenium concentrations (mg/kg dry weight) in plant species collected from Tranquillity, 1999 to 2003.

Species	N (ND)	Mean	Min	Max	SD factor
Acroptilon repens	1 (0)	0.39	0.39	0.39	-
Allenrolfea occidentalis	1 (0)	0.11	0.11	0.11	-
Atriplex argentea	44 (13)	<0.37	<0.20	1.90	1.88
Atriplex polycarpa	13 (3)	<0.39	<0.20	2.10	2.13
Atriplex spinifera	2 (1)	<0.22	<0.10	0.50	3.12
Avena sp.	17 (1)	<0.27	<0.10	0.50	1.55
Bassia hyssopifolia	2 (0)	1.10	0.71	1.70	1.85
Beta vulgaris	6 (1)	<0.46	<0.20	0.73	1.61
Bromus madritensis	13 (11)	<0.21	<0.20	0.43	1.24
Brassica nigra	54 (9)	<0.49	<0.20	3.50	2.16
Capsella bursa-pastoris	1 (0)	0.77	0.77	0.77	-
Chenopodium album	1 (0)	0.78	0.78	0.78	-
Chenopodium murale	1 (0)	0.20	0.20	0.20	-
Grindelia camporum	1 (0)	0.71	0.71	0.71	-
Helianthus annuus	1 (0)	0.36	0.36	0.36	-
Heliotropium curassavicum	8 (3)	<0.68	<0.20	3.90	3.77
Hordeum murinum	12 (4)	<0.31	<0.10	0.83	1.86
Hordeum vulgare	74 (19)	<0.30	<0.10	1.30	1.66
Isocoma acradenia	1 (0)	0.40	0.40	0.40	-
Lasthenia californica	2 (0)	0.61	0.31	1.20	2.60
Lactuca serriola	1 (0)	0.50	0.50	0.50	-
Malvella leprosa	1 (0)	0.41	0.41	0.41	-
Malva parviflora	1 (0)	0.20	0.20	0.20	-
Melilotus indica	11 (5)	<0.28	<0.20	0.40	1.33
Phacelia distans	7 (4)	<0.25	<0.20	0.40	1.33
Phalaris minor	2 (0)	0.20	0.20	0.20	1.00
Sesuvium verrucosum	3 (0)	0.65	0.20	1.70	2.96
Senecio vulgaris	1 (0)	0.74	0.74	0.74	-
Sisymbrium irio	25 (3)	<0.61	<0.20	2.40	2.04
Sonchus sp.	5 (0)	0.55	0.31	1.00	1.70
Suaeda moquinii	12 (1)	<0.93	<0.20	5.00	3.09

Table 3-3. Geometric means (Mean), sample size (N), number of non-detects (ND), minimum (Min), maximum (Max), and standard deviation factor (SD factor) of selenium concentrations (mg/kg dry weight) in plant species collected from Atwell Island, 2000 to 2002.

Species	N (ND)	Mean	Min	Max	SD factor
Atriplex argentea	16 (14)	<0.21	<0.20	0.40	1.22
Atriplex polycarpa	2 (2)	<0.20	<0.20	0.20	1.00
Avena sp.	4 (4)	<0.20	<0.20	0.20	1.00
Bromus madritensis	7 (6)	<0.22	<0.20	0.40	1.30
Brassica nigra	10 (6)	<0.23	<0.20	0.50	1.41
Cressa truxillensis	12 (10)	<0.21	<0.20	0.30	1.17
Distichlis spicata	6 (4)	<0.25	<0.10	1.40	2.45
Heliotropium curassavicum	4 (4)	<0.20	<0.20	<0.20	1.00
Hemizonia pungens	13 (11)	<0.17	<0.10	0.20	1.36
Hordeum murinum	18 (17)	<0.20	<0.10	0.30	1.21
Hordeum vulgare	20 (19)	<0.20	<0.20	0.30	1.09
Isocoma acradenia	1 (1)	<0.20	<0.20	<0.20	-
Lasthenia californica	3 (2)	<0.20	<0.20	0.20	1.00
Lactuca serriola	1 (0)	0.50	0.50	0.50	-
Melilotus indica	14 (14)	<0.19	<0.10	<0.30	1.33
Medicago sativa	1 (1)	<0.20	<0.20	<0.20	-
Sesuvium verrucosum	2 (1)	<0.20	<0.20	0.20	1.00
Sisymbrium irio	12 (10)	<0.21	<0.10	0.73	1.55
Spergularia macrotheca	1 (1)	<0.20	<0.20	<0.20	-
Suaeda moquinii	2 (1)	<0.20	<0.20	0.20	1.00

Table 3-4. Results of analysis of variance tests of selenium concentrations (mg/kg dry weight) between sample years in plant species collected from Tranquillity, 1999 to 2003. GM = geometric mean, N = sample size, ND = number of non-detects. *p* values marked with an asterisk must be interpreted with caution because of the high number of non-detects in one or more data sets.

Species	GM by sample year(N:ND) 1999	2000	2001	2002	2003	F	*p* value
Atriplex argentea	<0.49 (12:3)	<0.31 (15:6)	<0.29 (9:4)	-	0.48 (8:0)	2.33	0.09
Atriplex polycarpa	-	-	<0.33 (4:1)	<0.29 (4:2)	0.57 (5:0)	1.05	0.38*
Avena sp.	-	<0.30 (10:1)	-	-	0.23 (7:0)	4.11	0.06
Beta vulgaris	-	<0.39 (4:1)	-	-	0.62 (2:0)	1.35	0.31
Bromus madritensis	-	<0.20 (5:4)	<0.20 (6:6)	-	-	No variance*	
Brassica nigra	-	<0.47 (26:5)	<0.30 (12:4)	-	0.74 (16:0)	5.55	0.01
Heliotropium curassavicum	-	<1.41 (3:1)	-	-	0.98 (2:0)	0.96	0.49
Hordeum murinum	-	<0.22 (4:3)	-	-	<0.41 (7:1)	1.72	0.23*
Hordeum vulgare	<0.25 (10:3)	<0.28 (20:8)	<0.40 (16:2)	<0.26 (12:6)	<0.33 (16:0)	1.44	0.23*
Melilotus indica	-	-	<0.25 (8:5)	-	0.34 (2:0)	2.22	0.17*
Sisymbrium irio	-	-	-	<0.51 (14:3)	0.77 (11:0)	2.01	0.17
Suaeda moquinii	-	-	0.51 (5:0)	<1.19 (4:1)	1.82 (3:0)	1.45	0.29

Table 3-5. Results of Analysis of Variance tests of selenium concentrations (mg/kg dry weight) between sample years in plant species collected from Atwell Island, 2000 to 2002. GM = geometric mean, N = sample size, ND = number of non-detects. *p* values marked with an asterisk must be interpreted with caution because of the high number of non-detects in one or more data sets.

	GM by sample year (N:ND)				
Species	2000	2001	2002	F	*p* value
Atriplex argentea	<0.21 (10:9)	<0.21 (6:5)	-	0.00	0.99*
Bromus madritensis	-	<0.20 (3:2)	<0.25 (3:3)	0.57	0.60*
Cressa truxillensis	<0.22 (9:7)	-	<0.20 (3:3)	0.71	0.42*
Hemizonia pungens	<0.15 (8:7)	<0.20 (3:2)	<0.20 (2:2)	1.15	0.35*
Hordeum murinum	<0.19 (10:10)	<0.21 (6:5)	<0.20 (2:2)	0.93	0.41*
Hordeum vulgare	-	<0.20 (6:6)	<0.21 (14:13)	0.42	0.53*
Melilotus indica	<0.18 (10:10)	<0.20 (4:4)	-	0.32	0.58*
Sisymbrium irio	<0.17 (4:4)	-	<0.24 (8:8)	1.64	0.23*

Table 3-6. List of plant samples from Tranquillity that exceeded the population-level performance standard (2.0 mg/kg). Those marked with an asterisk had selenium levels that fell within the range of geometric means of vegetation collected from Kesterson NWR between 1988 and 1992 (2.3 to 6.7 mg/kg).

Collection Year	Species	Se concentration (mg/kg)
2000	*Heliotropium curassavicum*	3.9*
2000	*Heliotropium curassavicum*	3.6*
2001	*Suaeda moquinii*	2.6*
2002	*Suaeda moquinii*	4.4*
2002	*Sisymbrium irio*	2.4*
2002	*Suaeda moquinii*	2.3*
2003	*Atriplex polycarpa*	2.1
2003	*Suaeda moquinii*	5.0*
2003	*Brassica nigra*	3.5*
2003	*Brassica nigra*	3.2*
2003	*Heliotropium curassavicum*	2.3*

Seven plant species from Tranquillity and five plant species from Atwell Island were collected in sufficient numbers on various landforms (cultivated, uncultivated, and experimental lands) to allow an analysis of the affects of landform type on selenium levels (Tables 3-7 and 3-8). There were no clear differences in selenium levels between landform types for any species at Atwell Island, but this could be because of the generally low selenium levels and the high percentage of non-detects in the data sets. At Tranquillity, mean selenium levels in *A. argentea* were at least 40 percent lower on uncultivated lands than on cultivated or experimental lands ($p < 0.01$ and $p = 0.02$, respectively) and mean selenium levels in *B. nigra* were at least 50 to 70 percent lower on uncultivated lands than on experimental or cultivated lands ($p < 0.01$ and $p < 0.01$, respectively).

Table 3-7. Results of analysis of variance tests of selenium concentrations (mg/kg dry weight) between landform types in plant species collected from Tranquillity, 1999 to 2003. GM = geometric mean, N = sample size, ND = number of non-detects, Uncult = uncultivated lands, Cult = cultivated lands, Exp = experimental lands. *p* values marked with an asterisk must be interpreted with caution because of the high number of non-detects in one or more data sets.

	GM by landform(N:ND)				
Species	Uncult	Cult	Exp	F	*p* value
Atriplex argentea	<0.24 (16:9)	<0.39 (10:1)	<0.41 (12:3)	10.02	< 0.01*
Avena sp.	-	0.26 (7:0)	<0.28 (10:1)	0.15	0.70
Brassica nigra	<0.28 (22:8)	0.87 (16:0)	<0.58 (16:1)	17.04	< 0.01
Hordeum murinum	<0.23 (3:2)	0.57 (1:0)	<0.33 (8:2)	0.85	0.46*
Hordeum vulgare	0.20 (2:0)	<0.32 (48:8)	<0.27 (22:3)	1.49	0.22
Melilotus indica	0.27 (6:3)	0.28 (4:2)	0.36 (1:0)	0.43	0.66*
Sisymbrium irio	0.78 (3:0)	<0.47 (10:2)	<0.71 (12:1)	1.08	0.36

Table 3-8. Results of Analysis of Variance tests of selenium concentrations (mg/kg) between landform types in plant species collected from Atwell Island, 2000 to 2002. GM = geometric mean, N = sample size, ND = number of non-detects, Uncult = uncultivated lands, Cult = cultivated lands, Exp = experimental lands. *p* values marked with an asterisk must be interpreted with caution because of the high number of non-detects in one or more data sets.

	GM by landform (N:ND)				
Species	Uncult	Cult	Exp	F	*p* value
Atriplex argentea	<0.22 (13:11)	<0.20 (3:3)	-	0.44	0.52*
Hordeum murinum	<0.20 (15:14)	<0.20 (3:3)	-	0.02	0.88*
Hordeum vulgare	-	<0.21 (14:13)	<0.20 (6:6)	0.41	0.53*
Melilotus indica	<0.18 (11:11)	<0.20 (3:3)	-	0.22	0.65*
Sisymbrium irio	<0.22 (8:6)	-	<0.20 (4:4)	0.07	0.79*

There were no discernable differences in the selenium concentration between plant parts (whole plant, vegetation, and fruits) from plants collected from Atwell Island, but there were clear differences in the selenium concentration between plants parts in two species collected from Tranquillity (Tables 3-7 and 3-9). In *H. murinum* the whole plant had 61 percent less selenium than the fruits ($p < 0.01$) yet in *H. vulgare* the fruits had 24 percent less selenium than the vegetative structures. There is some evidence that the fruits of *Phacelia distans* had about 40 percent less selenium than the vegetative structures and that the fruits of *Sonchus* sp. had about 60 percent less selenium than the vegetative structures. The small sample sizes (and high numbers of non-detects in the *P. distans* data) are reason to interpret the findings for these two species with caution. There also is some evidence that the fruits of *A. argentea* were higher in selenium than other parts of the plant and that the vegetative structures of *M. indica* were lower in selenium than the whole plant.

Table 3-9. Results of Analysis of Variance tests of selenium concentrations (mg/kg) between plant parts in plant species collected from Tranquillity, 1999 to 2003. GM = geometric mean, N = sample size, ND = number of non-detects, Whole = whole plant, Veg = vegetation. *p* values marked with an asterisk must be interpreted with caution because of the high number of non-detects in one or more data sets.

	GM by plant part (N:ND)				
Species	Whole	Veg	Fruits	F	*p* value
Atriplex argentea	<0.35 (19:5)	<0.35 (22:8)	0.84 (3:0)	2.87	0.07
Avena sp.	<0.30 (10:1)	0.22 (3:0)	0.24 (4:0)	0.86	0.44
Bromus madritensis	<0.20 (6:5)	-	<0.22 (7:6)	0.85	0.38*
Brassica nigra	-	<0.55 (27:4)	<0.43 (27:5)	1.26	0.27
Hordeum murinum	<0.22 (5:4)	0.26 (3:0)	0.57 (4:0)	4.73	0.04*
Hordeum vulgare	-	<0.34 (40:8)	<0.26 (34:11)	6.04	< 0.01
Melilotus indica	0.36 (3:0)	<0.25 (8:5)	-	4.62	0.06*
Phacelia distans	<0.20 (1:1)	<0.33 (3:2)	<0.20 (3:1)	15.62	< 0.01*
Sisymbrium irio	-	<0.79 (12:1)	<0.49 (13:2)	3.12	0.09
Sonchus sp.	-	0.71 (2:0)	0.31 (2:0)	806.35	< 0.01

Table 3-10. Results of Analysis of Variance tests of selenium concentrations (mg/kg) between plant parts in plant species collected from Atwell Island, 2000 to 2002. GM = geometric mean, N = sample size, ND = number of non-detects, Whole = whole plant, Veg = vegetation. *p* values marked with an asterisk must be interpreted with caution because of the high number of non-detects in one or more data sets.

	GM by plant part (N:ND)				
Species	Whole	Veg	Fruits	F	*p* value
Atriplex argentea	<0.21 (10:9)	<0.21 (6:5)	-	0.00	0.99*
Avena sp.	-	<0.20 (2:2)	<0.20 (2:2)	No variance*	
Bromus madritensis	<0.25 (3:3)	-	<0.20 (3:2)	0.57	0.60*
Brassica nigra		<0.28 (5:1)	<0.20 (5:5)	2.58	0.15*
Hemizonia pungens	<0.16 (10:9)	<0.20 (3:2)	-	1.09	0.32*
Hordeum murinum	<0.19 (12:12)	-	<0.21 (6:5)	1.74	0.21*
Hordeum vulgare	-	<0.18 (10:10)	<0.20 (10:7)	1.00	0.33*
Melilotus indica	<0.18 (10:10)	<0.20 (4:4)	-	0.32	0.58*
Sisymbrium irio	<0.17 (4:4)	<0.28 (4:4)	<0.20 (4:3)	1.42	0.29*

3.3.2. Invertebrates

The mean selenium concentrations in crickets (Figure 3-1) collected from Tranquillity (0.40 to 0.81 mg/kg) were higher than those collected from Atwell Island (0.13 to 0.49 mg/kg; $p < 0.01$). Selenium levels in crickets did not appear to vary between years at Atwell Island, but did at Tranquillity. The mean selenium concentration in crickets collected in 1999 was 44 percent lower than in those collected in 2000, 51 percent lower than in those collected in 2001, and 47 percent lower than in those collected in 2003 ($p = 0.2$, $p < 0.01$, and $p = 0.01$, respectively).

The mean selenium concentrations in beetles (Figure 3-2) collected from Tranquillity (0.65 to 1.35 mg/kg) were higher than those collected from Atwell Island (0.14 to 0.85 mg/kg, $p < 0.01$). The mean concentration of selenium in beetles varied between years at both sites. At the Tranquillity site, beetles were approximately 50 percent lower in selenium in 2002 than in 2000 and 2001 ($p = 0.02$ and $p = 0.01$, respectively) and at Atwell Island the selenium concentration in beetles was more than four times higher in 2000 than in 2001 and 2002 ($p < 0.01$ and $p = 0.02$). However, the high number of non-detects in the Atwell Island 2000 data set (8 of 10 samples) coupled with a high detection limit for some samples (4 samples had a detection limit of 2.0 mg/kg) makes this apparent relationship uncertain.

The mean selenium concentrations in spiders (Figure 3-3) were higher at Tranquillity (1.27 to 2.24 mg/kg) than at Atwell Island (0.25 to 1.04 mg/kg, $p < 0.01$). The mean concentration of selenium in spiders did not appear to vary between years at Tranquillity. At Atwell Island, selenium in spiders was almost twice as high in 2000 as in 2001 ($p = 0.03$) and more than four times higher than in 2002 ($p < 0.01$). These apparent relationships are uncertain because of the non-detects in the 2000 data set.

The mean selenium concentrations in isopods (Figure 3-4) were much higher at Tranquillity (1.04 to 3.47 mg/kg) than at Atwell Island (0.13 to 0.48 mg/kg, $p < 0.01$). The mean concentration of selenium in isopods appeared to vary between years at both sites. The mean concentration of selenium in isopods collected from Tranquillity in 2002 was approximately 70 percent less than those collected in 2000, 2001, and 2003 ($p < 0.01$ in all cases). At Atwell Island, the mean concentration of selenium in isopods was approximately 4 times greater in 2000 than in 2002 ($p < 0.01$), but this relationship is uncertain because of the number of non-detects in the 2000 and 2002 data sets.

The mean concentration of selenium in all invertebrate groups (crickets, beetles, spiders, and isopods) collected from Atwell Island remained below the performance standard of 2.0 mg/kg established for project lands (Figures 3-1, 3-2, 3-3, and 3-4; FWS 1999). Furthermore, only one spider sample and one isopod sample exceeded the performance standard. At Tranquillity, the mean concentration of selenium in invertebrates also remained below the performance standard, except for the spiders that were collected in 1999 and isopods that were collected in every year except 2002. Twelve isopod samples, 8 spider samples, 3 beetle samples and 0 cricket samples collected from Tranquillity exceeded the performance standard. It is not unexpected that spiders and isopods exceeded the performance standard. The performance standard established was for terrestrial invertebrates as a group. Spiders are predators and isopods are detritus feeders;

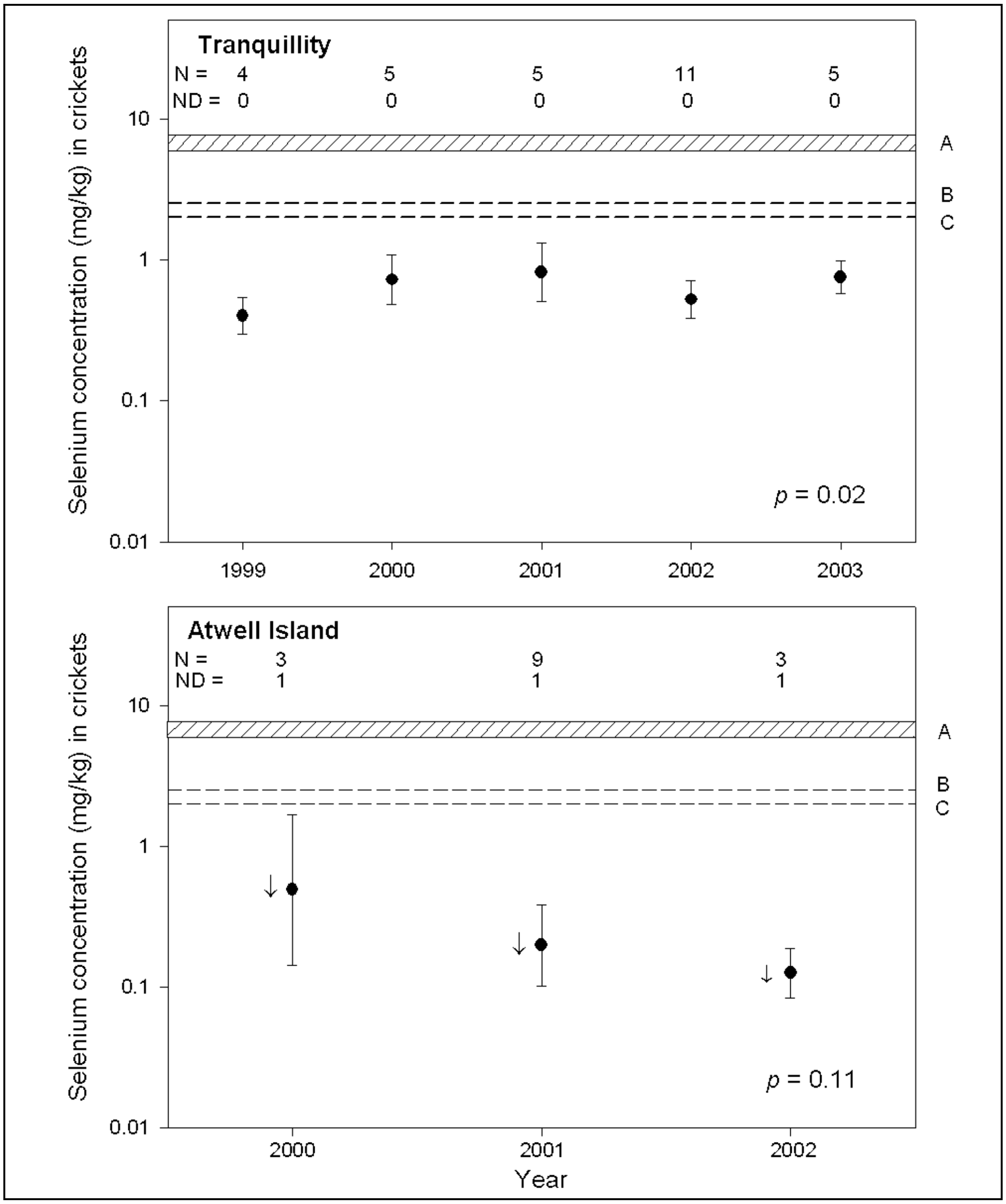

Figure 3-1. Geometric means (solid circles) and error bars (mean multiplied by and divided by one standard deviation factor) of selenium concentrations in crickets collected from the Tranquillity and Atwell Island study sites. Data points that exceed the performance standard are represented by open circles. The ↓ signifies a mean lower than that reported because of the occurrence of non-detects in the data set. A = the range of geometric means of selenium concentrations in crickets (5.9 to 7.6 mg/kg) collected from 1988 to 1992 in grassland habitat at Kesterson NWR (USDI 1992). B = background level of selenium in terrestrial invertebrates (2.5 mg/kg) collected from non-seleniferous soils in the western United States (USDI 1998). C = the performance standard set by the U.S. Fish and Wildlife Service for selenium concentrations in terrestrial invertebrates (2.0 mg/kg) for Land Retirement Demonstration Project lands (FWS 1999).

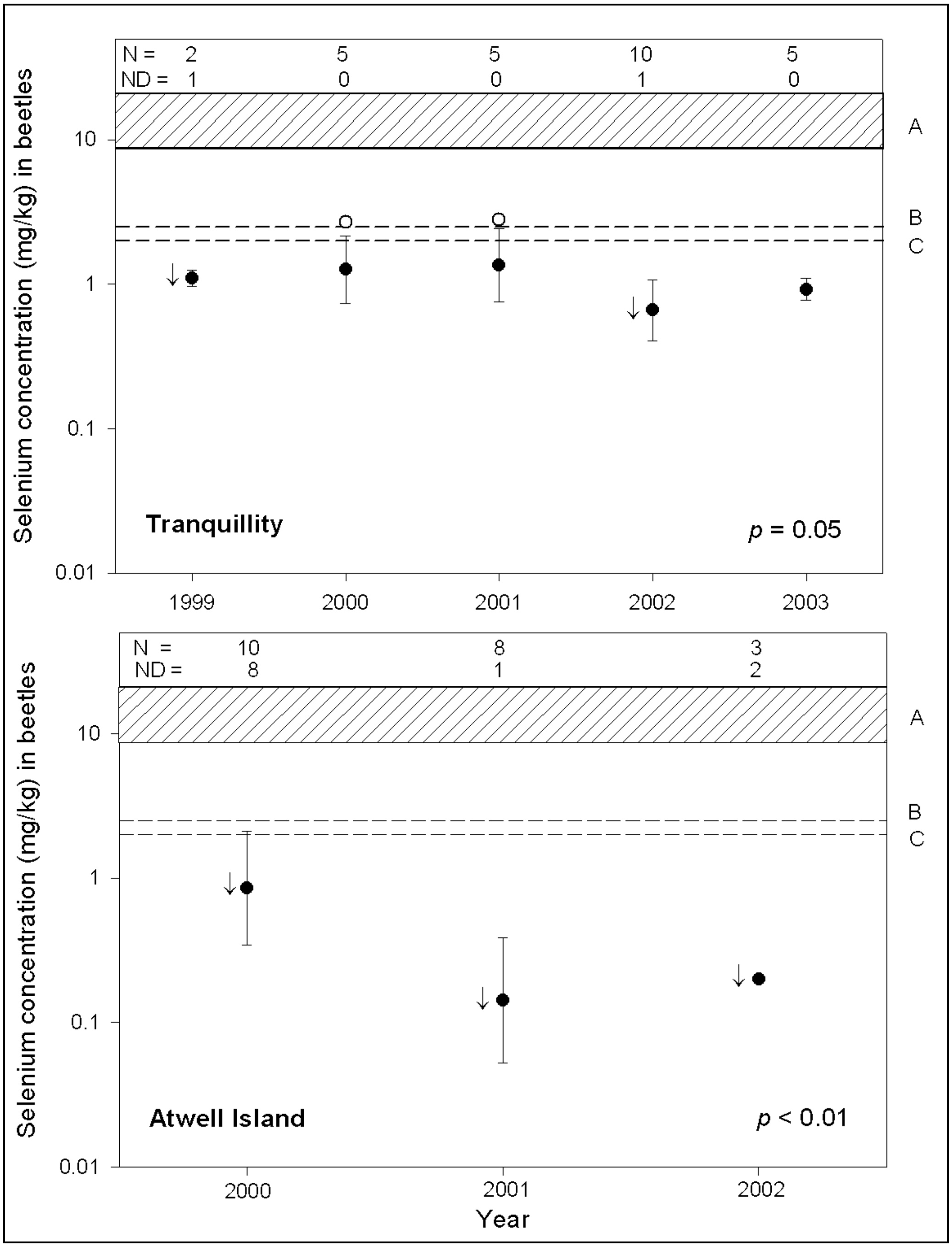

Figure 3-2. Geometric means (solid circles) and error bars (mean multiplied by and divided by one standard deviation factor) of selenium concentrations in beetles collected from the Tranquillity and Atwell Island study sites. Data points that exceed the performance standard are represented by open circles. The ↓ signifies a mean lower than that reported because of the occurrence of non-detects in the data set. A = the range of geometric means of selenium concentrations in beetles (8.7 to 21.0 mg/kg) collected from 1988 to 1992 in grassland habitat at Kesterson NWR (USDI 1992). B = background level of selenium in terrestrial invertebrates (2.5 mg/kg) collected from non-seleniferous soils in the western United States (USDI 1998). C = the performance standard set by the FWS for selenium concentrations in terrestrial invertebrates (2.0 mg/kg) for LRDP lands (FWS 1999).

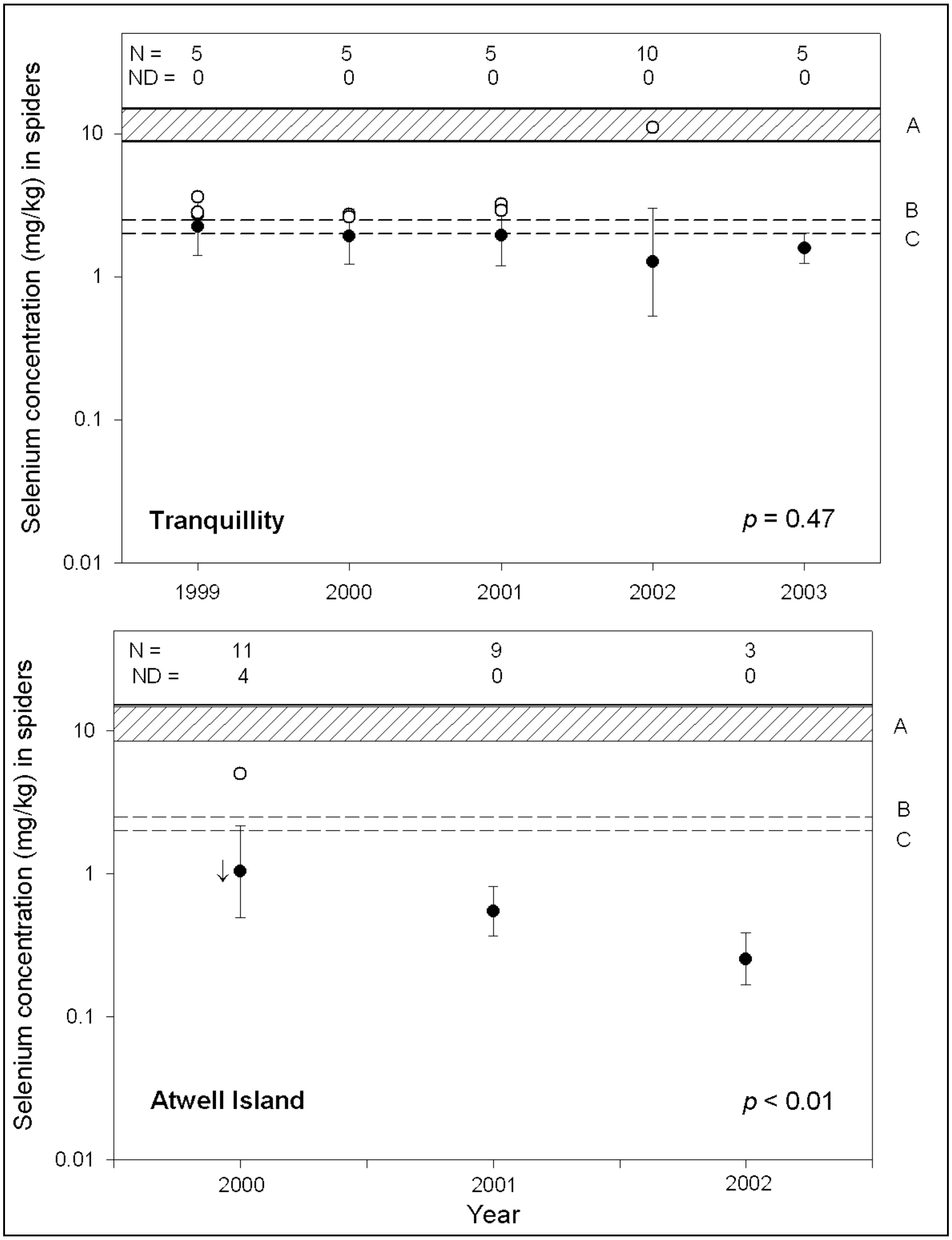

Figure 3-3. Geometric means (solid circles) and error bars (mean multiplied by and divided by one standard deviation factor) of selenium concentrations in spiders collected from the Tranquillity and Atwell Island study sites. Data points that exceed the performance standard are represented by open circles. The ↓ signifies a mean lower than that reported because of the occurrence of non-detects in the data set. A = the range of geometric means of selenium concentrations in spiders (8.8 to 15.0 mg/kg) collected from 1988 to 1992 in grassland habitat at Kesterson NWR (USDI 1992). B = background level of selenium in terrestrial invertebrates (2.5 mg/kg) collected from non-seleniferous soils in the western United States (USDI 1998). C = the performance standard set by FWS for selenium concentrations in terrestrial invertebrates (2.0 mg/kg) for LRDP lands (FWS 1999).

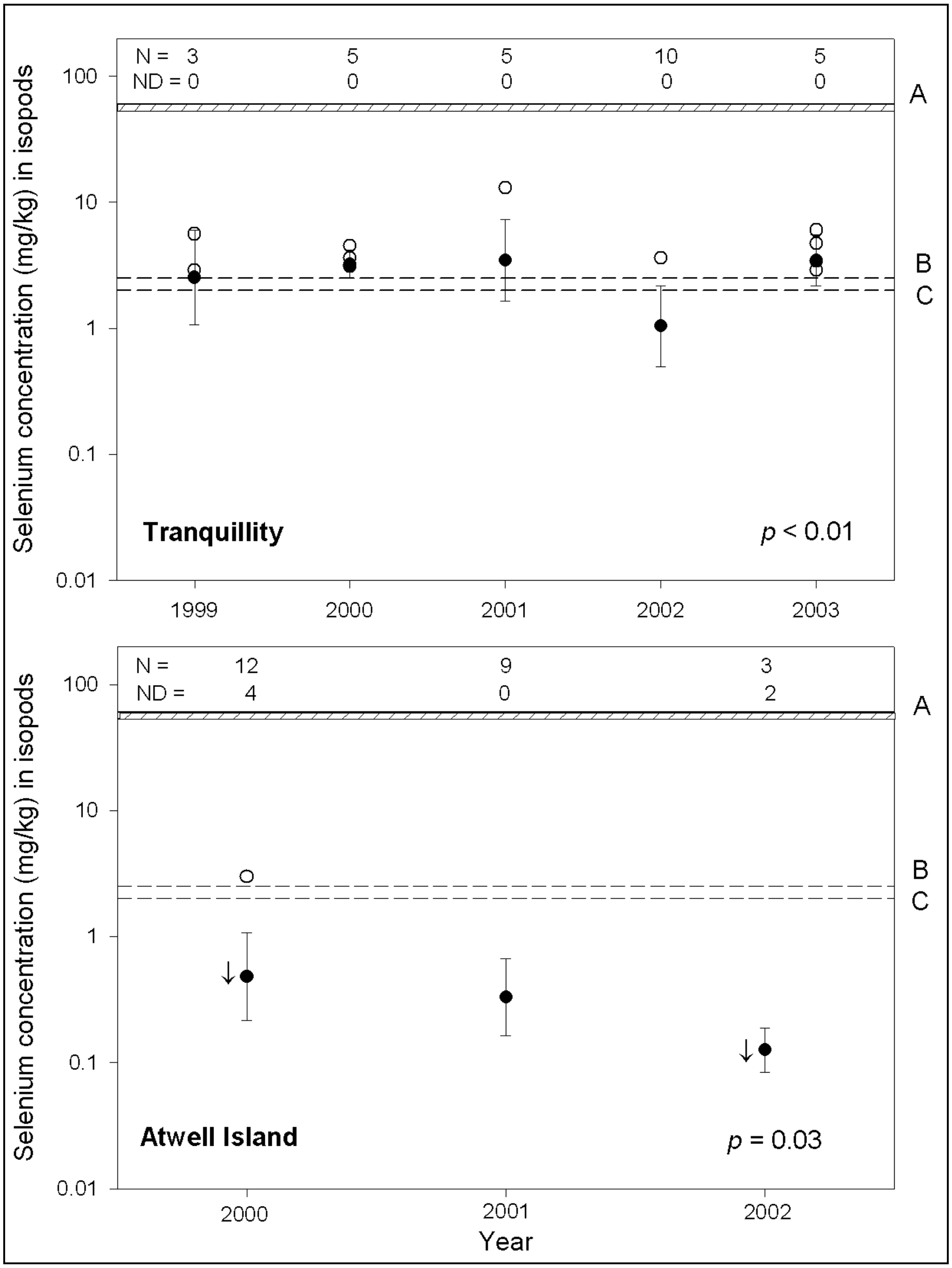

Figure 3-4. Geometric means (solid circles) and error bars (mean multiplied by and divided by one standard deviation factor) of selenium concentrations in isopods collected from the Tranquillity and Atwell Island study sites. Data points that exceed the performance standard are represented by open circles. The ↓ signifies a mean lower than that reported because of the occurrence of non-detects in the data set. A = the range of geometric means of selenium concentrations in isopods (53.0 to 60.0 mg/kg) collected from 1988 to 1992 in grassland habitat at Kesterson NWR (USDI 1992). B = background level of selenium in terrestrial invertebrates (2.5 mg/kg) collected from non-seleniferous soils in the western United States (USDI 1998). C = the performance standard set by FWS for selenium concentrations in terrestrial invertebrates (2.0 mg/kg) for LRDP lands (FWS 1999).

both would be expected to accumulate more selenium than herbivorous or granivorous terrestrial invertebrates and, indeed, isopods are known to accumulate high amounts of selenium (USDI 1992).

The mean selenium concentrations in terrestrial invertebrates collected from both sites generally remained within the range for terrestrial invertebrates occurring on non-seleniferous soils in the western United States (2.5 mg/kg, USDI 1998). The only exception to this was at Tranquillity where isopods exceeded this range in all years but 2002. The selenium levels in all invertebrate groups collected from the Tranquillity and Atwell Island sites are approximately an order of magnitude less than corresponding invertebrate groups collected between 1988 and 1992 in grassland habitat at Kesterson NWR.

3.3.3. Small Mammals

The mean selenium concentrations in deer mouse (*Peromyscus maniculatus*) bodies (Figure 3-5) were higher at Tranquillity (0.89 to 1.34 mg/kg) than at Atwell Island (0.62 and 0.68 mg/kg, $p < 0.01$). The mean concentration of selenium in deer mouse bodies did not appear to vary between years at Atwell Island site, but at Tranquillity, deer mouse bodies had approximately 34 percent less selenium in 2001 than in 2003 ($p < 0.01$). Similarly, the mean selenium concentrations in deer mouse livers (Figure 3-6) were higher at Tranquillity (2.27 to 3.90 mg/kg) than at Atwell Island (2.21 to 2.37 mg/kg, $p < 0.01$). The concentration of selenium in deer mouse livers did not appear to vary between years at Atwell Island site, but at Tranquillity, deer mouse livers had approximately 30 to 42 percent less selenium in 2001 than in other years ($p \leq 0.01$ for all years). The concentrations of selenium in deer mice clearly differed between irrigated and nonirrigated landforms (Figure 3-7). The greatest difference was in 2001 when deer mouse body tissues from non-irrigated sites had 47 percent less selenium than those from irrigated sites and deer mouse liver tissues from nonirrigated sites had 50 percent less selenium than those from irrigated sites.

Selenium levels in deer mouse bodies collected from both Tranquillity and Atwell Island (Figure 3-7) were within the range that is typically found in small mammals occurring on non-seleniferous soils in the western United States (2.0 mg/kg, USDI 1998). Selenium levels in deer mouse bodies collected from both Tranquillity and Atwell Island were an order of magnitude less than selenium levels found in deer mouse bodies collected from grassland habitats at Kesterson NWR from 1988 to 1992. Selenium levels in deer mouse livers collected from Tranquillity and Atwell Island (Figure 3-7) were within the range of selenium levels found in small mammal livers collected near a selenium-normal wetland (between 1 and 10 mg/kg, USDI 1998) located in the San Joaquin Valley. Selenium levels in deer mouse livers from both sites also were within or slightly above the range of selenium concentrations in small mammal livers (< 3 mg/kg) collected from an agroforestry plantation located in the San Joaquin Valley (Clark 1987). No performance standards were set by FWS for small mammal body or

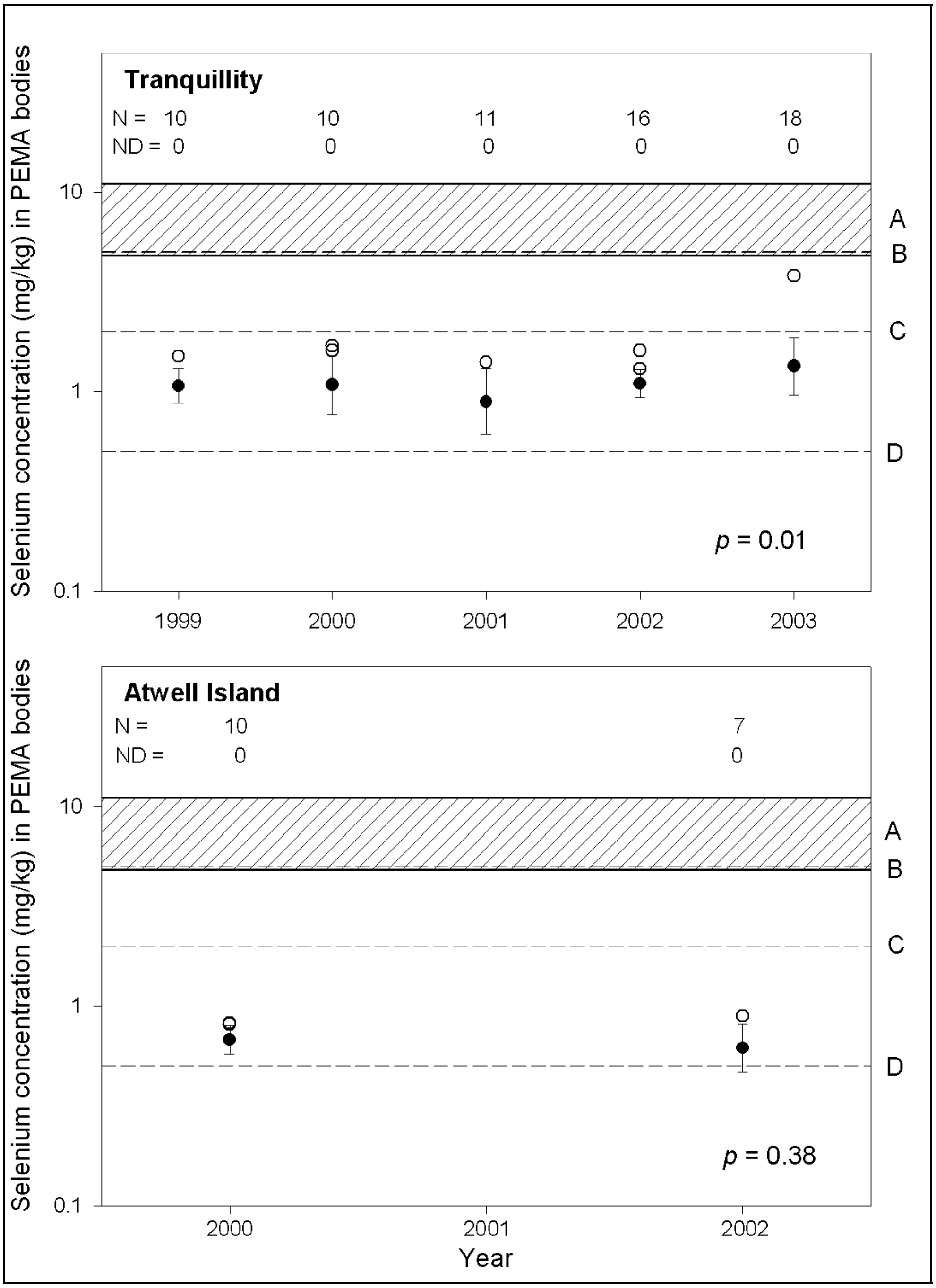

Figure 3-5. Geometric means (solid circles) and error bars (mean multiplied by and divided by one standard deviation factor) of selenium concentrations in deer mouse (PEMA) bodies collected from Tranquillity and Atwell Island. Data points that exceed the mean multiplied by one standard deviation factor are represented by open circles. A = the range of geometric means of selenium concentrations in deer mouse bodies (4.8 to 11.0 mg/kg) collected at Kesterson NWR from 1988 to 1992 (USDI 1992). B = the performance standard established for rodent hair for this project (5.0 mg/kg). C = background level of selenium in small mammal bodies (2.0 mg/kg) collected from non-seleniferous soils in the western United States (USDI 1998). . D = the performance standard established for rodent blood for this project (0.5 mg/kg).

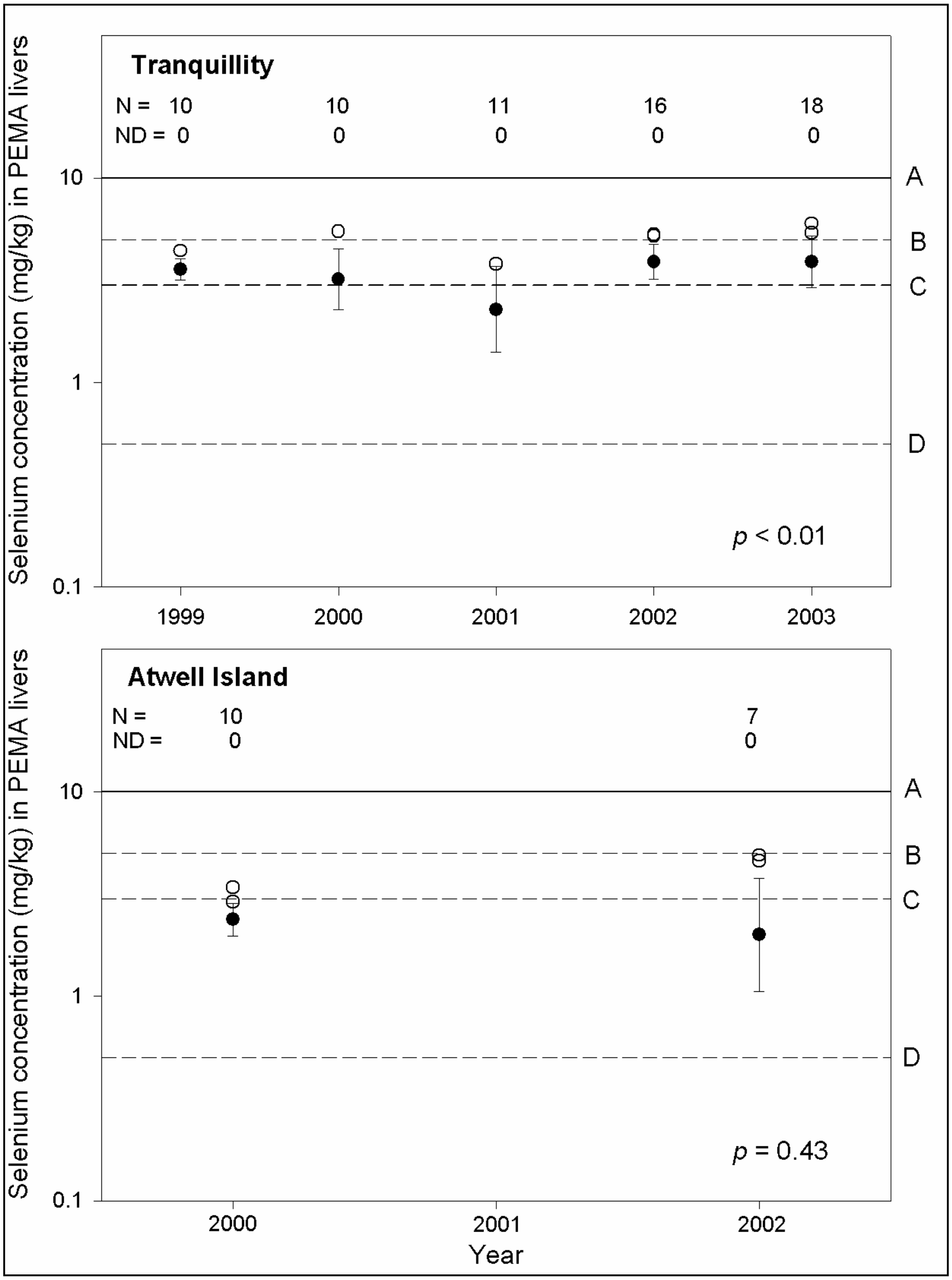

Figure 3-6. Geometric means (solid circles) and error bars (geometric mean multiplied by and divided by one standard deviation factor) of selenium concentrations in deer mouse (PEMA) livers collected from Tranquillity and Atwell Island. Data points that exceed the mean multiplied by one standard deviation factor are represented by open circles. A = the upper range of selenium in small mammal livers collected from near a selenium-normal wetland (between 1 and 10 mg/kg, Clark 1987). B = the performance standard established for rodent hair for this project (5.0 mg/kg). C = the upper range of selenium concentrations in small mammal livers collected from an agroforestry plantation (< 3 mg/kg, CDFG 1993). D = the performance standard established for rodent blood for this project (0.5 mg/kg).

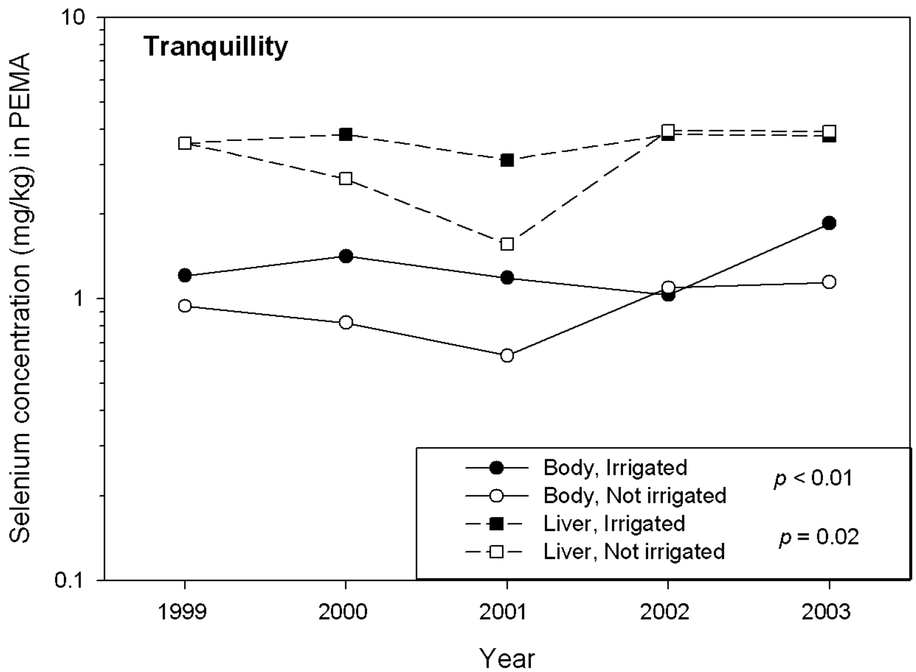

Figure 3-7. Geometric means of selenium concentrations in deer mouse (PEMA) bodies and livers collected from irrigated and non-irrigated lands at Tranquillity, 1999 to 2003.

liver tissues. Instead, performance standards were set for small mammal blood (0.5 mg/kg) and hair (5.0 mg/kg). The selenium values obtained from deer mouse bodies exceeded the values established for blood and the selenium levels obtained for livers were less than the performance standards set for hair. Nevertheless, the selenium levels present in the bodies and livers of deer mice appear to be within acceptable limits.

The mean selenium concentrations in shrew (*Sorex ornatus*) bodies collected from Tranquillity varied from 1.95 to 2.51 mg/kg (Figure 3-8). There were no discernable differences in selenium concentrations between years. Livers were not extracted from the bodies of shrews in 1999, so no data from that year are available for analysis. However, the mean selenium concentrations in shrew livers varied from 2.00 to 4.18 mg/kg (Figure 3-9) from 2000 to 2002 and there were clear differences between years. The selenium concentration in shrew liver tissue was 63 percent lower in 2002 than in 2000 ($p < 0.01$) and 45 percent lower than in 2001 ($p = 0.03$). This may be misleading, however, because of the small sample size (n = 1) of shrew livers analyzed in 2002.

The mean selenium concentrations in shrew bodies collected from Tranquillity (Figure 3-9) were near the upper level of the range of selenium in small mammal body tissues collected from non-seleniferous soils in the western United States (generally < 2.0 mg/kg, USDI 1998). This is not unexpected because shrews are

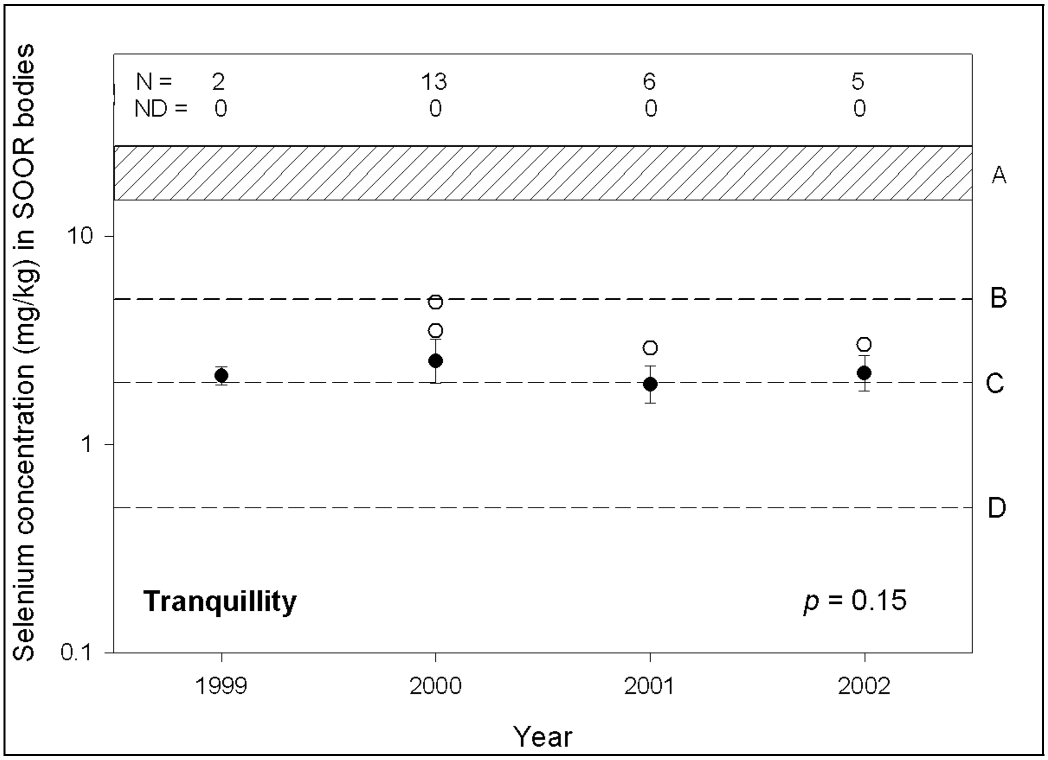

Figure 3-8. Geometric means (solid circles) and error bars (geometric mean multiplied by and divided by one standard deviation factor) of selenium concentrations in shrew (SOOR) bodies collected from Tranquillity. Data points that exceed the geometric mean multiplied by one standard deviation factor are represented by open circles. A = the range of geometric means of selenium concentrations in shrew bodies (15.0 to 27.0 mg/kg) collected at Kesterson NWR from 1988 to 1992 (USDI 1992). B = the performance standard established for rodent hair for this project (5.0 mg/kg). C = background level of selenium in small mammal bodies (2.0 mg/kg) collected from non-seleniferous soils in the western United States (USDI 1998). D = the performance standard established for rodent blood for this project (0.5 mg/kg).

insectivores and bio-accumulation of selenium in shrews is expected to be greater than in most other small mammals. The mean selenium levels in shrews collected from Tranquillity were approximately an order of magnitude less than selenium levels found in shrews collected between 1988 and 1992 from grassland habitats at Kesterson NWR (15.0 to 27.0 mg/kg). No performance standards were set for small mammal body tissues by the FWS. Instead, performance standards were set for small mammal blood (0.5 mg/kg) and hair (5.0 mg/kg). The selenium in shrew bodies collected from the Tranquillity site exceeded those established for blood, but were lower than the standard established for hair. Selenium levels in the livers of shrews collected from Tranquillity (Figure 3-9) were within the range of selenium levels found in the livers of small mammals (between 1 and 10 mg/kg) collected from near a selenium-normal wetland located in the San Joaquin Valley. Selenium levels in the livers of shrews collected from Tranquillity were also near the upper range of selenium levels found in small mammal livers (< 3 mg/kg) collected from an agroforestry plantation in the San Joaquin Valley (Clark

1988). Accordingly, the selenium levels present in the bodies and livers of deer mice appear to be within acceptable limits.

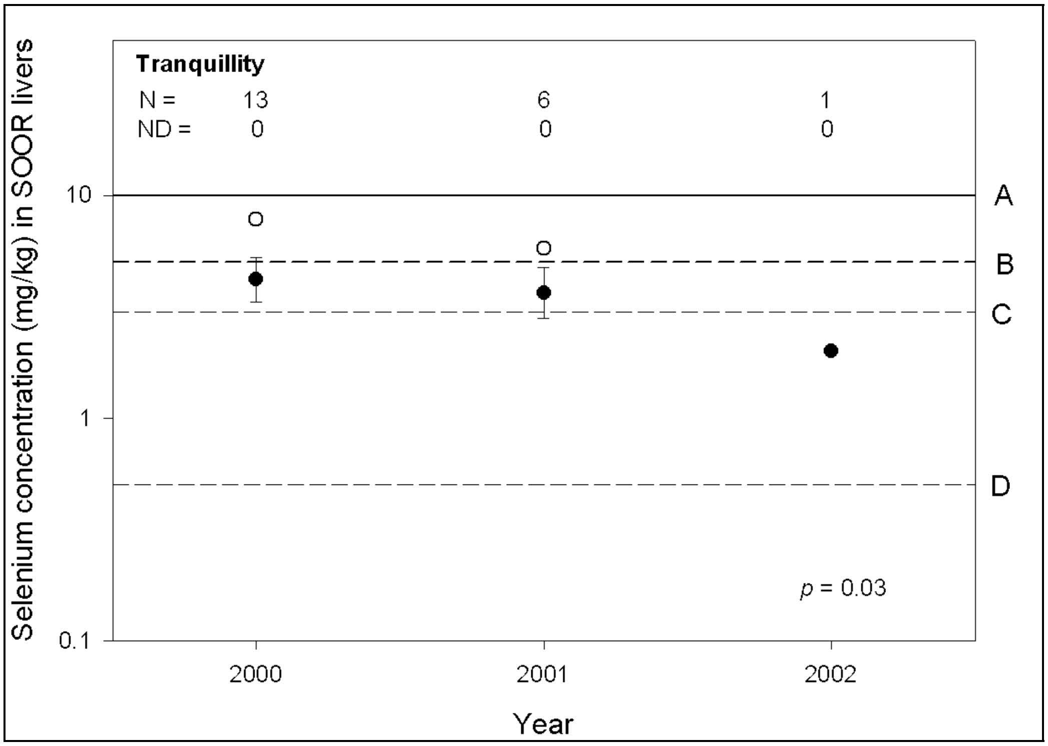

Figure 3-9. Geometric means (solid circles) and standard deviations of selenium concentrations in shrew (SOOR) livers collected from the Tranquillity study site. Data points that exceed the standard deviation are represented by open circles. A = the upper range of selenium in small mammal livers collected from near a selenium-normal wetland (between 1 and 10 mg/kg, Clark 1987). B = the performance standard established for rodent hair for this project (5.0 mg/kg). C = the upper range of selenium in small mammal livers collected from an agroforestry plantation (< 3 mg/kg, CDFG 1993). D = the performance standard established for rodent blood for this project (0.5 mg/kg).

3.4. Discussion and Conclusions

The concentrations of selenium observed in biota at both project sites are generally considered to be within acceptable limits and, although a risk assessment model was not generated, there is evidence of low risk to wildlife. Whereas high selenium levels in groundwater could result in a potential risk to biota, the exposure pathway is limited because the depth to groundwater has increased. Similarly, although selenium levels in the soils remain elevated (but show evidence of decline), the extremely dry conditions that prevail at both Atwell Island and Tranquillity may limit the exposure pathway. The physical conditions present on these sites are thought to be representative of other drainage impacted areas of the San Joaquin Valley and it is reasonable to assume that the bio-accumulation of selenium and risk to wildlife would be similar to that found on our study sites.

There is less risk of exposure to selenium at Atwell Island than at Tranquillity because of lower levels of selenium in the soils and groundwater. Mean selenium levels in biota on both project sites tend to be within the range typically found in biota occurring on non-seleniferous soils in the western United States and are generally below the population-level performance standards set for the project by the FWS (FWS 1999). Furthermore, selenium levels in biota from both sites are generally an order of magnitude less than found at Kesterson NWR.

The generally low levels of selenium in biota may be a result of very low water availability during the study period. Precipitation was below normal or near-normal; ephemeral pools (pools of water lasting 30 days or more) were never present, and the team suspects that soil moisture was too low to allow a high degree of selenium uptake. There were no wetlands on the Tranquillity site. Both project sites were primarily dry, upland environments rather than aquatic or wetland environments, which likely reduces the potential for the bio-availability and bio-accumulation of selenium.

The assumption that reduced water availability results in lowered selenium accumulation also is supported by the higher selenium levels observed in some biota from irrigated lands compared with selenium levels present in biota from non-irrigated lands. This trend was evident in some of the most common and widespread species present on the Tranquillity site: *A. argentea, B. nigra*, and in the bodies and livers of deer mice. These observations suggest that retiring lands from irrigated agriculture may reduce the potential for selenium bio-accumulation at the population level.

Although the mean selenium concentrations in biota were generally below the performance standards, some samples within specific groups exceeded those standards. Eleven of 325 (3.4 %) plant samples and 22 of 115 (19.1 %) invertebrate samples (mostly isopods and spiders) collected from Tranquillity exceeded performance standards and 2 of 83 (2.4%) invertebrate samples collected from Atwell Island exceeded performance standards (see Table 3-6 and Figures 3-1 through 3-4). Although performance standards were not set for small mammal bodies and livers, some samples collected from both Tranquillity and Atwell Island appeared to be somewhat high in selenium (see Figures 3-5, 3-6, 3-8, and 3-9). In many cases, these samples were collected from areas known to be rich in selenium (e.g., areas with high selenium levels in the soil or sediments within the San Luis Drain). These samples are reason for caution.

The Tranquillity site is reasonably representative of conditions found on other drainage impacted lands within the region (i.e., those lands that could potentially be retired from irrigated agriculture). Tranquillity clay—the predominant soil type at the site—is the most extensive soil type mapped by the Natural Resources

Conservation Service on the lower alluvial fan and basin rim landforms in the western San Joaquin Valley. Selenium levels in the soil and groundwater (prior to retirement) were similar to other drainage impacted lands in the region (see Chapter 2) and the vegetation and habitat characteristics that developed on the site (exclusive of successfully restored areas) appear to be similar to that occurring on fallowed lands within the region. We expect that our results are regionally applicable and would be indicative of conditions on other retired lands.

We contend that land retirement and the restoration of retired lands, if properly implemented, monitored, and managed, would be beneficial to wildlife, including threatened and endangered species, and would generally not pose a severe risk of selenium exposure. However, we urge that land retirement be integrated with a comprehensive selenium monitoring program to monitor exposure of wildlife to selenium on a site by site basis. Furthermore, a suite of remedial actions should be developed in the event that selenium exposure on a site is or becomes problematic.

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