ELEMENTAL CONCENTRATIONS IN THE LIVERS AND KIDNEYS OF WINTER FLOUNDER (*PSEUDOPLEURONECTES AMERICANUS*) AND ASSOCIATED SEDIMENTS FROM VARIOUS LOCATIONS IN THE BRAS D'OR LAKE, NOVA SCOTIA, CANADA

C.L. Chou, B.M. Zwicker, J.D. Moffatt, and L. Paon

Marine Environmental Sciences Division
Oceans Branch
Department of Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

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Elemental concentrations in the livers and kidneys of winter flounder (*Pseudopleuronectes americanus*) and associated sediments from various locations in the Bras d'Or Lake, Nova Scotia, Canada.

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C.L. Chou , B.M. Zwicker , J.D. Moffatt and L. Paon

Marine Environmental Sciences Division
Science Branch
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, N.S., Canada
B2Y 4A2

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ABSTRACT

Between May-June 1997, flounder and sediments were collected from 5 sites in the Bras d'Or Lake, Cape Breton, Nova Scotia: Baddeck Bay, Denys Basin, East Bay, Nyanza Bay, and Whycocomagh Bay. Flounder kidney and liver and associated sediments were analysed for 21 elements: antimony (Sb), arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lanthanum (La), lead (Pb), lithium (Li), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), strontium (Sr), thallium (Tl), titanium (Ti), uranium (U), vanadium (V), and zinc (Zn). Organic carbon content in the sediments (superficial muds) was also determined. Results were ranked for geographical distributions of metals, metal concentration results were compared with biological parameters, and inter-relationships of metals within and between liver and kidney, and between liver and kidney and sediments, were examined. Data for several of the elements presented in this study, particularly in the kidney, were not previously reported in the literature.

Rankings for geographic distribution of metals were similar for liver and kidney, but were generally unrelated to sediment metal concentration ranking. However Cd, Cu, and Mn were the only metals in flounder that had a good correspondence with sediment concentrations, implying that flounder kidney and liver may reflect the geographic distributions of these 3 metals in the Bras d'Or Lakes. For liver and kidney metals, East Bay ranked first, whereas, Baddeck Bay had the most elevated rank, based on sediment metals. Sediment Ni concentrations were elevated at some sites, but the source of Ni discharge is not known. For the 5 survey sites, sediment organic carbon was weakly related to metal concentrations. Arsenic concentration in flounder liver had a wide variation among the sites, and was 5 times higher in East Bay than in Denys Basin. Metal concentrations were higher in liver than in kidney, with the exceptions of Be, Li, Se, and Sr. Cadmium, Co, Mo, and Ni in liver showed inter-relationships and were inversely related to liver weight. Silver, Cu, Mn, and Se were inter-related in the liver. Kidney Cu, Mo, and Ti showed an inverse relationship with kidney weight and inter-relationships between Mn and As, and between Tl and U were also observed. Positive relationships between concentrations of Cd, Cu, Mo, Pb, U, and V in the kidney and liver were observed, suggesting these metals were proportionally assimilated by these organs. The physiological effects of metal interactions in flounder require furthur investigation, especially Ag, Cu, Mn, and Se.

RÉSUMÉ

Entre mai et juin 1997, nous avons prélevé des échantillons de plies et de sédiments à cinq sites du lac Bras d'Or, au Cap-Breton, en Nouvelle-Écosse : baie de Baddeck, bassin Denys, baie East, baie Nyanza et baie Whycocomagh. Nous avons analysé les reins et les foies de plies et les sédiments associés pour y rechercher les 21 éléments suivants : antimoine (Sb), argent (Ag), arsenic (As), béryllium (Be), cadmium (Cd), chrome (Cr), cobalt (Co), cuivre (Cu), lanthane (La), lithium (Li), manganèse (Mn), molybdène (Mo), nickel (Ni), plomb (Pb), sélénium (Se), strontium (Sr), thallium (Tl), titane (Ti), uranium (U), vanadium (V) et zinc (Zn). Nous avons également mesuré la teneur en carbone organique des sédiments (vases superficielles). Les résultats ont été classés selon la distribution géographique des métaux; nous avons comparé les résultats concernant les concentrations de métaux aux paramètres biologiques; nous avons aussi

examiné les interrelations des métaux dans et entre le foie et le rein, et entre le foie, le rein et les sédiments. Les données concernant plusieurs des éléments présentés dans notre étude, particulièrement dans le rein, n'avaient encore jamais été signalées dans la littérature.

Les classements de la distribution géographique des métaux étaient semblables pour le foie et le rein, mais de façon générale n'étaient pas reliés au classement des concentrations de métaux dans les sédiments. Toutefois, Cd, Cu, et Mn étaient les seuls métaux mesurés chez les plies qui présentaient une bonne correspondance avec les concentrations dans les sédiments, ce qui signifie que le foie et le rein de plie pourraient indiquer la distribution géographique de ces trois métaux dans le lac Bras d'Or. En ce qui concerne les concentrations de métaux dans le foie et le rein de plie, la baie East venait au premier rang, tandis que la baie de Baddeck était le premier site pour la concentration de métaux dans les sédiments. Les concentrations de Ni étaient fortes à certains sites, mais la source du rejet de ce métal est inconnue. Aux cinq sites de relevé, le carbone organique était faiblement relié aux concentrations de métaux. La concentration d'arsenic dans le foie de plie, qui variait considérablement d'un site à l'autre, était cinq fois plus haute dans la baie East que dans le bassin Denys. Les concentrations de métaux étaient plus hautes dans le foie que dans le rein, à l'exception de Be, Li, Se et Sr. Dans le foie, Cd, Co, Mo et Ni montraient des interrelations et étaient en proportion inverse du poids du foie. Dans le foie également, Ag, Cu, Mn et Se étaient interreliés. Dans le rein, Cu, Mo et Ti présentaient une relation inverse avec le poids du rein, et on notait des interrelations entre Mn et As, et entre Tl et U. Des relations positives entre les concentrations de Cd, Cu, Mo, Pb, U et V dans le rein et le foie ont été observées, ce qui permet de penser que ces métaux étaient assimilés de façon proportionnelle par ces organes. Les effets physiologiques des interactions des métaux chez la plie appelle un complément de recherche, notamment en ce qui concerne Ag, Cu, Mn et Se.

1.0. INTRODUCTION

The Bras d'Or Lake, Cape Breton, Nova Scotia is connected to the Atlantic ocean by 3 channels. As a result of restricted access to the ocean and freshwater inflow, the salinity of the Lake is in the range of 20-26 $^0/_{00}$ (Gurbutt and Petrie, 1995). This "inland sea" is inhabited by marine and anadromous species including at least 22 species of marine teleost fish (McKay, 1975), crustaceans and edible shellfish (mussels, oysters, clams). The Bras d'Or Lake supports a small-scale commercial lobster fishery, finfish and molluscan aquaculture, as well as active sport and domestic fisheries.

The physical oceanography of the Bras d'Or Lake system has been studied by Krauel (1975) and early biological studies included an examination of the life cycle and biology of mysids (Black, 1958; Scott and Black, 1960); an investigation of Foraminifera (Vilks, 1967); a study of the flora of the Bras d'Or Lake (McLachlin and Edelstein, 1971); and a bacteriology survey which was prompted by concerns regarding dumping of untreated sewage (Drinnan, 1974). Since the early 1970's, biological investigations have explored the potential for aquaculture in the Bras d'Or Lake (McKay, 1975). Determinations of certain metal concentrations in mussels and oysters (Young, 1973), in seawater, in silts from streams running into the Bras d'Or Lakes, and in stream water and bed loadings, have been reported (Young, 1974) but, generally, little information regarding metallic concentrations in Bras d'Or marine organisms or sediments is available.

In any environment, baseline metal level databases are invaluable, because they provide a benchmark for the assessment of environmental quality in that area. This is of particular importance in relatively pristine areas that may be threatened by increases in industrial activity. Benthic organisms such as flatfish, are often investigated for their applicability as indicators of environmental metal levels (Fletcher *et al.*, 1981). Flatfish commonly bury themselves in the sediments when not feeding and can accumulate contaminants from the sediments which they inhabit. This report focuses on metal concentrations in winter flounder (*Pseudopleuronectes americanus*) and associated sediments from five sites in the Bras d'Or Lake, Cape Breton, Nova Scotia, Canada, and is part of an on-going project aimed at mapping the background levels of metals in sediments and marine biota collected from harbours throughout the Scotia-Fundy Region. In this report, winter flounder and sediment samples were collected at 5 sites in the Bras d'Or Lake: Baddeck Bay (BB), Denys Basin (DB), East Bay (EB), Nyanza Bay (NB), and Whycocomagh Bay (WB). Sediments and flounder tissues: kidney and liver, were analyzed for the following 21 metals: antimony (Sb), arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lanthanum (La), lead (Pb), lithium (Li), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), strontium (Sr), thallium (Tl), titanium (Ti), uranium (U), vanadium (V), and zinc (Zn).

2.0. MATERIALS AND METHODS

2.1. SAMPLING

Between May/June 1997 (Figure 1), flounder were caught while trawling using a 50-foot flounder net with a mesh size of 12 mm. The exact site determination was governed by topography because trawling could only be performed on a relatively flat bottom, in the absence of large rocks and debris. Ideally, fish of a standard size are collected, and this sampling design is intended to limit the variation of results attributable to flounder size. However, availability of flounder varied from site to site. As such, 16 flounder were collected both at Baddeck and Nyanza Bays; 18 were collected at East Bay; and 20 were collected at each of Denys Basin and Whycocomagh Bay, and weights ranged from 267-748g.

Upon collection, flounder were placed in a continuous-flow seawater tank onboard ship and were processed on the date of collection: i.e. once back in port, flounder were sexed, weighed, and measured for length. The liver and kidney were extracted and a muscle sample was obtained using stainless steel scissors and tweezers. The organs were weighed, placed in Whirl-pak© plastic bags, and stored in an onboard freezer.

In preparation for sample digestion, individual samples of flounder kidney and liver, from each site, were homogenized using a stainless steel Polytron homogenizer. After homogenization, 1g portions of each of liver and kidney samples were pooled, to yield 1 pooled sample per organ, per sampling site. Pooled samples were then homogenized, and stored at –27 °C to await analysis.

1.0g of each kidney and liver pool were weighed out into 50mL plastic centrifuge tubes for digestion. 5.0mL concentrated HNO_3 (Fisher Optima) was added, and all sample pools were microwave digested using a domestic microwave oven (power: 900 Watts). To prevent fumes from entering the chamber, sample tubes were contained in a Nordicware microwave cooker. The sample digestion protocol consisted of 3 stages: (1) 1 minute at 40 power (2) 2 minutes at 40 power (3) 5 minutes at 40 power. A Teflon© beaker containing 50mL water was placed in the oven at each stage to protect the microwave. After digestion, samples were diluted to 25mL with de-ionized water for analysis.

Sediment samples were collected using a VanVeen grab sampler (approximate capacity of 0.015 m^3). Sediments were collected from the same site at which the flounder were caught. Sediments were removed from the grab using a stainless steel scoop, transferred to clean plastic Whirl-pak© bags and frozen. Only the top 10 cm of the sediment was sampled. The samples were transported back to the lab and stored at -27°C to await analysis.

Sediment samples, consisting of surficial muds, were dried in an oven for 24 hours at ~60°C, ground using an agate mortar and pestle, and microwave digested in 50mL plastic centrifuge tubes using 6 mL concentration HF and 1 mL concentration HNO_3. 0.2g samples were used for digestion. Microwave digestion conditions were the same as for flounder tissues. Following digestion, the samples were diluted to 50mL with de-ionized water.

2.2. CHEMICAL ANALYSES

All trace metal analyses, with the exception of Ag, As and Se, were carried out using a Perkin-Elmer SCIEX ELAN 5000 ICP-MS. The system is equipped with a four-channel mass flow controller to stabilize all plasma gas flows. A corrosion-resistant spray chamber (Ryton), a cross-flow nebulizer and a Perkin-Elmer Model AS 90 random access autosampler were used. Ag, As and Se were determined by a high temperature graphite furnace atomic absorption spectrophotometry method using a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer equipped with HGA-2000 controller (Chou and Uthe, 1978). All concentrations are listed as µg/g wet weight for tissues, and dry weight for sediments.

2.3. ORGANIC CARBON

Organic carbon content was determined for sediments from all 5 sites according to the procedure of Loring and Rantala (1992). The method differentiates humus matter from extraneous sources of organic carbon such as graphite and coal.

2.4. DATA MANIPULATION

Data were entered into Microsoft Excel for Windows 95, Version 7.0a (1995) spreadsheet and graphs and tables were constructed. Maps were generated on Adobe Acrobat. For each metal, pooled data were inspected for trends.

Figure 1. Site map

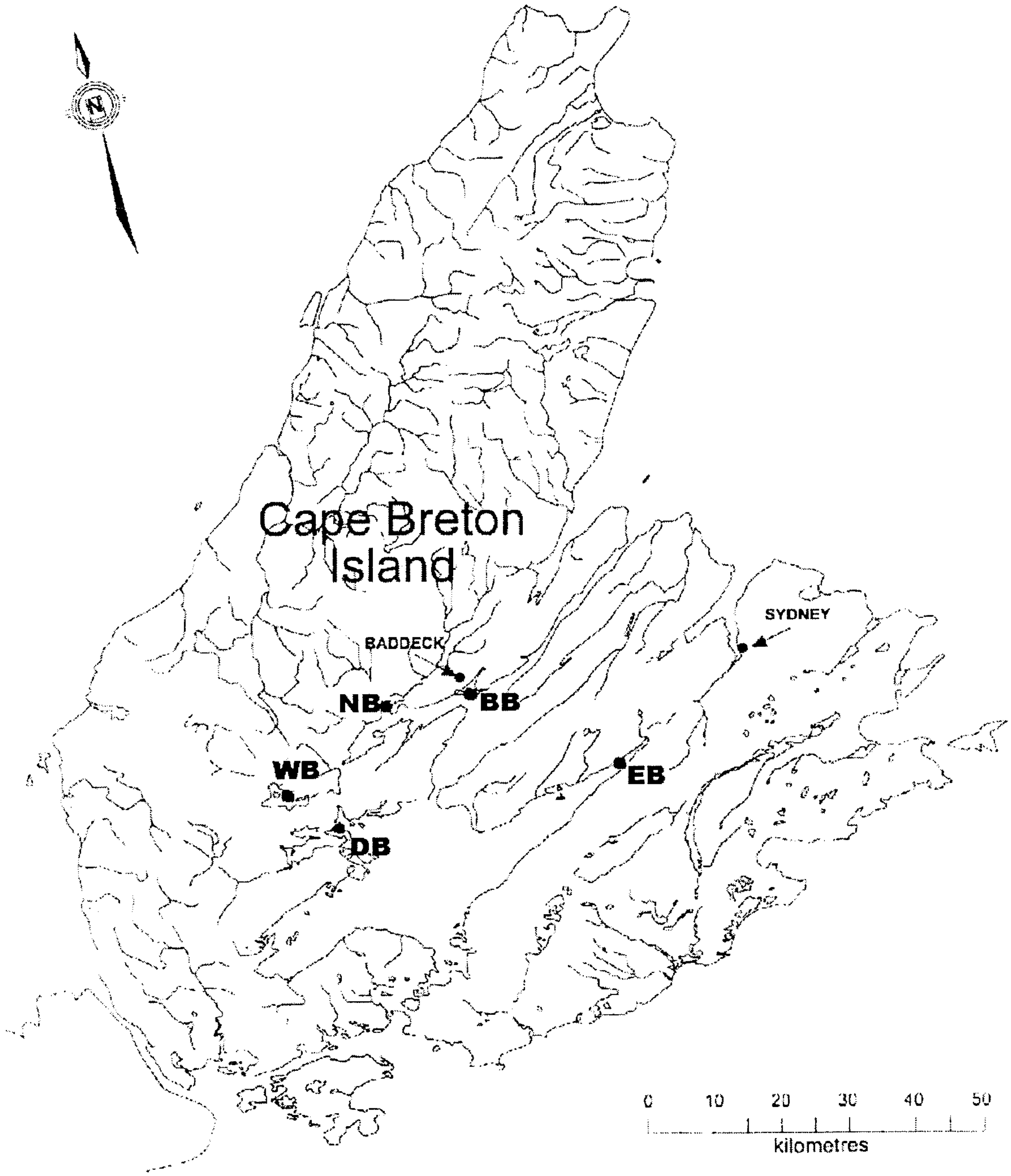

Figure 1. Site map.

3.0. RESULTS

3.1. BIOLOGICAL PARAMETERS

Although, ideally, flounder of approximately equivalent size were to be collected from each site, in accordance with the sampling design and in order to reduce size effect on contaminant data, mean weights of the flounder that were ultimately collected at each site varied due to availability (Figure 2). The mean length range for flounder was (306mm ± 16) - (362.5mm ± 30). Nyanza Bay flounder were longest and Whycocomagh Bay flounder were shortest. Baddeck Bay (342mm ± 24), Denys Basin (331mm ± 15.5) and East Bay flounder (326mm ± 16) were of intermediate lengths (Table 1).

Flounder total mean weights ranged from the highest value in Nyanza Bay samples (511g ± 116) to the lowest weight in Whycocomagh Bay flounder (328g ± 42). Baddeck Bay (486g ± 106), Denys Basin (445g ± 57), and East Bay (424g ± 71) samples had intermediate mean total weights.

The relative distribution of flounder mean liver weights at each site was the same as the relative length and weight distributions. Maximum mean liver weight occurred in Nyanza Bay flounder (7.7g ± 2.8), and the minimum occurred in flounder from Whycocomagh Bay (3.6g ± 1.1). Baddeck Bay (6.8g ± 3.5), Denys Basin (6.7g ± 2.0), and East Bay (5.0g ± 1.7) flounder had intermediate liver weights.

By comparison with other biological parameters, the relative distribution of mean kidney weights matched other parameters, with the exception of Denys Basin flounder kidney, which were slightly heavier than the Baddeck Bay value, i.e., by only 0.1g. The mean kidney weight range was (1.9g ± 0.4) - (2.9g ± 1.0), and weight was highest in Nyanza Bay samples and lowest in Whycocomagh Bay flounder. Denys Basin (2.6g ± 0.5), Baddeck Bay (2.5g ± 0.9), and East Bay (2.3g ± 0.6) had intermediate kidney weights. Figure 2. illustrates a positive relationship between mean flounder length, total weight, liver and kidney weights.

Table 1. Mean total weight (g), liver weight (g), kidney weight (g) and length (mm) for flounder from 5 sites in the Bras d'Or Lake, Cape Breton, Nova Scotia.

LOCATION	Total Wt. (g)	Liver Wt. (g)	Kidney Wt. (g)	Total Lgt. (mm)
Baddeck Bay	486±106	6.8±3.5	2.5±0.9	342±24
Denys Basin	445±57	6.7±2.0	2.6±0.5	362.5±30
East Bay	424±71	5.0±1.7	2.3±0.6	331±15.5
Nyanza Bay	511±116	7.7±2.8	2.9±1.0	306±16
Whycocomagh Bay	328±42	3.6±1.1	1.9±0.4	326±16

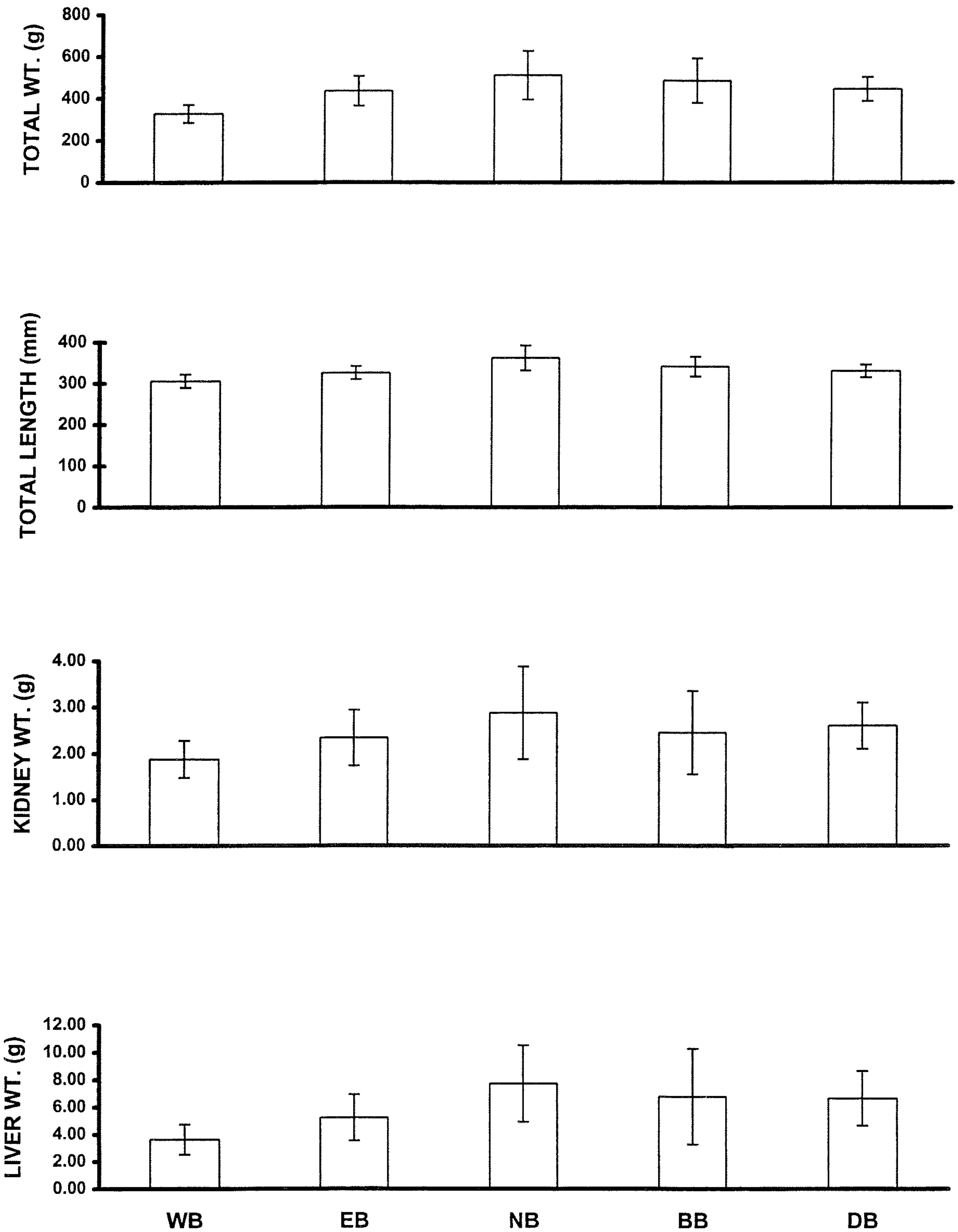

Figure 2. Total mean weight (g), length (mm), kidney weight (g) and liver weight (g) in flounder from Whycocomagh Bay, East Bay, Nyanza Bay, Baddeck Bay, and Denys Basin, Bras d'Or Lake, Nova Scotia.

3.2. METAL CONCENTRATIONS

Concentrations for 21 metals in flounder from 5 sites were summarized and presented for liver, kidney and sediments. The results show 1) metal concentration ranges 2) metal concentration data for each site, from highest to lowest.

3.2.1. LIVER

Table 2. summarizes the concentrations of antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, lanthanum, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, titanium, uranium, vanadium, and zinc, in flounder liver tissue. Data is presented for Baddeck Bay (BB), Denys Basin (DB), East Bay (EB), Nyanza Bay (NB), and Whycocomagh Bay (WB).

Antimony (Sb): not detected

Arsenic: (Fig. 3a)
Arsenic concentration ranged from 6.55-30.10μg/g. The highest arsenic concentration occurred in flounder from East Bay (30.10μg/g). Intermediate values were found in the livers of flounder collected at Baddeck Bay (15.77μg/g) and Whycocomagh Bay (8.01μg/g). Concentration in Nyanza Bay flounder liver was (7.52μg/g). The lowest arsenic concentration was determined in flounder from Denys Basin (6.55μg/g).
Relative order of arsenic concentrations at each site:
EB>BB>WB>NB>DB

Beryllium: (Fig. 3a)
Beryllium concentration in flounder liver ranged from 0.01-0.05μg/g. Whycocomagh Bay flounder had the highest beryllium liver concentration (0.05μg/g). Baddeck Bay flounder had a similar concentration of 0.05μg/g. Denys Basin flounder had a concentration of 0.04μg/g Be in the liver. East Bay flounder had 0.03μg/g, and beryllium concentration in the livers of Nyanza Bay flounder were 0.01μg/g.
Relative order of beryllium concentrations at each site:
WB>BB>DB>EB>NB

Cadmium: (Fig. 3b)
Cadmium concentration in flounder liver ranged from 0.39-0.93μg/g. Highest concentration was found in flounder from Whycocomagh Bay (0.93μg/g). East Bay had a slightly lower concentration (0.86μg/g). Intermediate concentrations were determined in Nyanza Bay (0.58μg/g) and Baddeck Bay samples (0.53μg/g). Denys Basin flounder had the lowest concentration (0.39μg/g).
Relative order of cadmium concentrations at each site:
WB>EB>NB>BB>DB

Chromium: (Fig. 3b)
Chromium ranged between 0.59-0.72μg/g in flounder. Baddeck and Denys Basin flounder had equal concentrations of chromium in the liver (0.72μg/g). East Bay (0.68μg/g) and Nyanza Bay (0.64μg/g) had comparable values. Whycocomagh Bay flounder had the lowest concentration of chromium in the liver (0.59μg/g).
Relative order of chromium concentrations at each site:
BB>DB>EB>NB>WB

Cobalt: (Fig. 3b)
In flounder liver, cobalt concentration ranged from 0.28-0.65μg/g. The highest concentration occurred in flounder collected at Whycocomagh Bay (0.65μg/g). Levels in flounder from East Bay were slightly lower (0.52μg/g). Baddeck Bay flounder had a concentration of 0.33μg/g. The lowest concentrations were determined in flounder collected from Denys Basin (0.29μg/g) and Nyanza Bay (0.28μg/g).
Relative order of cobalt concentrations at each site:
WB>EB>BB>DB>NB

Copper: (Fig. 3c)
Copper concentration ranged from 7.51-13.6μg/g. The highest copper concentration was found in livers of flounder collected at East Bay (13.6μg/g). Baddeck Bay flounder had a liver concentration of 13.1μg/g. Whycocomagh Bay (11.3μg/g) and Denys Basin (10.2μg/g) values were slightly lower. Lowest values were determined in flounder collected at Nyanza Bay (7.51μg/g).
Relative order of copper concentrations at each site:
EB>BB>WB>DB>NB

Lanthanum: (Fig. 3c)
Lanthanum concentration ranged from undetectable levels to 0.024μg/g. Highest concentrations were found in East Bay flounder (0.024μg/g). Whycocomagh flounder had a liver lanthanum value of about half (0.012μg/g). Baddeck Bay concentrations were lower (0.004μg/g). Lanthanum concentrations were not detected in samples from Nyanza Bay and Denys Basin.
Relative order of lanthanum concentrations at each site:
EB>WB>BB>NB=DB

Lead: (Fig. 3e)
Lead concentrations ranged from 0.01-0.16μg/g. The highest lead concentration occurred in samples from Baddeck Bay (0.16μg/g). The second highest concentration was found in East Bay flounder (0.13μg/g). Nyanza and Whycocomagh Bay had intermediate lead concentrations (0.03μg/g). Lowest concentrations were determined in samples from Denys Basin (0.01μg/g).
Relative order of lead concentrations at each site:
BB>EB>NB=WB>DB

Lithium: (Fig. 3c)
Lithium ranged between 0.05-0.07μg/g. Denys Basin had the highest lithium value (0.07μg/g). Nyanza Bay had a comparable value of 0.07μg/g. East Bay had a slightly lower liver lithium

concentration of 0.06µg/g. Baddeck Bay had a liver concentration of 0.06µg/g, and flounder from Whycocomagh Bay had a liver lithium concentration of 0.05µg/g.
Relative order of lithium concentrations at each site:
DB>NB>EB>BB>WB

Manganese: (Fig. 3d)
Manganese concentration ranged from 1.39-2.05µg/g. East Bay flounder had the highest concentration of liver manganese (2.05µg/g). Whycocomagh Bay (1.83µg/g) and Baddeck Bay (1.80µg/g) had similar levels. Nyanza Bay had a concentration of 1.46µg/g, and Denys Bay had the lowest concentration of liver manganese: 1.39µg/g.
Relative order of manganese concentrations at each site:
EB>WB>BB>NB>DB

Molybdenum: (Fig. 3d)
Molybdenum concentration ranged from 0.13-0.23µg/g. The highest molybdenum concentration occurred in flounder from Whycocomagh Bay (0.23µg/g). Lower values were found in flounder from East Bay (0.18µg/g) and Nyanza Bay (0.15µg/g). Lowest values were determined in flounder collected from Baddeck Bay (0.14µg/g) and Denys Bay (0.13µg/g).
Relative order of molybdenum concentrations at each site:
WB>EB>NB>BB>DB

Nickel: (Fig. 3d)
Nickel ranged between 0.34-1.27µg/g. Whycocomagh Bay flounder had the highest liver concentration (1.27µg/g). Flounder collected at East Bay had a lower concentration of 1.17µg/g. Baddeck Bay flounder 0.44µg/g. Lowest nickel values occurred in flounder from Denys Basin (0.38µg/g) and Nyanza Bay (0.34µg/g).
Relative order of nickel concentrations at each site:
WB>EB>BB>DB>NB

Selenium: (Fig. 3e)
Selenium ranged from 2.05-3.31µg/g in flounder liver. Highest concentration was found in flounder from East Bay (3.31µg/g). Baddeck Bay (2.53µg/g) and Whycocomagh Bay (2.21µg/g) had similar selenium values. A concentration of 2.20µg/g occurred in Denys Basin samples. The lowest concentration was found in Whycocomagh Bay samples (2.05µg/g).
Relative order of selenium concentrations at each site:
NB>BB>EB>DB>WB

Silver: (Fig. 3a)
Silver ranged from 0.15-0.54µg/g. Highest concentration was in flounder from East Bay (0.54µg/g), followed by Baddeck Bay (0.51µg/g), Whycocomagh Bay (0.38µg/g) Denys Basin (0.20µg/g), and Nyanza Bay (0.15µg/g). Relative order of silver concentrations at each site:
EB>BB>WB>DB>NB

Strontium: (Fig. 3e)
Strontium concentration ranged between 0.35-0.81µg/g. The highest concentration occurred in flounder collected at East Bay (0.80µg/g). Denys Basin flounder had lower concentrations (0.50µg/g), followed by flounder from Whycocomagh Bay (0.50µg/g). Lowest values were determined in flounder from Baddeck Bay (0.39µg/g) and Nyanza Bay (0.35µg/g).
Relative order of strontium concentrations at each site:
EB>DB>WB>BB>NB

Thallium: (Fig. 3f)
Thallium concentrations ranged from 0.002-0.006µg/g. The highest concentration was found in flounder from East Bay (0.006µg/g). Equal values were determined in liver samples collected from Whycocomagh and Nyanza Bays and Denys Basin (0.003µg/g). The lowest value, 0.002µg/g, was determined in Baddeck Bay flounder.
Relative order of thallium concentrations at each site:
EB>WB=NB=DB>BB

Titanium: (Fig. 3f)
Titanium ranged from 0.22-0.39µg/g. East Bay flounder had the highest titanium concentrations in the liver (0.39µg/g). Whycocomagh Bay flounder were lower (0.34µg/g). Denys Bay flounder had a concentration of 0.27µg/g in the liver. Baddeck Bay (0.23µg/g) and Nyanza Bay (0.22µg/g) flounder had the lowest concentrations of titanium in the liver.
Relative order of titanium concentrations at each site:
EB>WB>DB>BB>NB

Uranium: (Fig.3f)
Uranium ranged from 0.004-0.024µg/g. The highest value was found in flounder from East Bay (0.024µg/g). Second highest concentration was found in flounder from Whycocomagh Bay (0.019µg/g), followed by Denys Basin (0.017µg/g). Nyanza Bay samples had a concentration of 0.013µg/g. Baddeck Bay flounder had the lowest concentration of uranium (0.004µg/g).
Relative order of uranium concentrations at each site:
EB>WB>DB>NB>BB

Vanadium: (Fig. 3g)
Vanadium ranged between 0.38-2.03µg/g in flounder. Baddeck Bay flounder had the highest concentration of vanadium in the liver (2.03µg/g), followed by East Bay samples (0.96µg/g). Nyanza and Whycocomagh Bays had similar values: 0.80µg/g and 0.76µg/g, respectively. Denys Basin flounder had a vanadium concentration of about half this value: 0.38µg/g.
Relative order of vanadium concentrations at each site:
BB>EB>NB>WB>DB

Zinc: (Fig. 3g)
Zinc concentrations ranged from 37.7-44.1µg/g. The highest concentration (44.1µg/g) occurred in the liver of flounder from Baddeck Bay. Denys Basin (42.6µg/g) and Nyanza Basin flounder (42.4µg/g) had similar liver zinc levels. Whycocomagh Bay flounder had a concentration of 41.1µg/g. The lowest concentration occurred in East Bay samples (37.7µg/g).

Relative order of zinc concentrations at each site:
BB>DB>NB>WB>EB

Table 2. Metal concentrations (µg/g wet weight) in liver of flounder collected at 5 sites in the Bras d' Or Lake, Cape Breton, Nova Scotia.

Metal	BB	DB	EB	NB	WB	Range
Ag	0.51	0.20	0.54	0.15	0.38	0.15-0.54
As	15.77	6.55	30.10	7.52	8.01	6.55-30.10
Be	0.05	0.04	0.03	0.01	0.05	0.01-0.05
Cd	0.53	0.39	0.86	0.59	0.93	0.39-0.93
Co	0.33	0.29	0.52	0.28	0.65	0.28-0.65
Cr	0.72	0.72	0.68	0.65	0.59	0.59-0.72
Cu	13.1	10.2	13.6	7.51	11.3	7.51-13.6
La	0.004	nd	0.024	nd	0.012	0-0.024
Li	0.06	0.07	0.06	0.07	0.05	0.05-0.07
Mn	1.80	1.39	2.05	1.46	1.83	1.39-2.05
Mo	0.14	0.13	0.18	0.15	0.23	0.13-0.23
Ni	0.44	0.38	1.17	0.34	1.27	0.34 -1.27
Pb	0.16	0.01	0.13	0.03	0.03	0.01-0.16
Sb	nd	nd	nd	nd	nd	
Se	2.53	2.20	3.31	2.05	2.21	2.05-3.31
Sr	0.35	0.50	0.81	0.39	0.50	0.35 -0.81
Ti	0.23	0.27	0.39	0.22	0.34	0.22 -0.39
Tl	0.002	0.003	0.006	0.003	0.003	0.002-0.006
U	0.004	0.017	0.024	0.013	0.019	0.004-0.024
V	2.03	0.38	0.96	0.80	0.77	0.38 -2.03
Zn	44.1	42.6	37.7	42.4	41.1	37.7-44.1

Figure 3. Metal concentrations (μg/g) in flounder liver: a) Ag, As and Be b) Cd, Co, Cr c) Cu, La, and Li d) Mn, Mo and Ni e) Pb, Se, and Sr f) Ti, Tl and U g) V and Zn

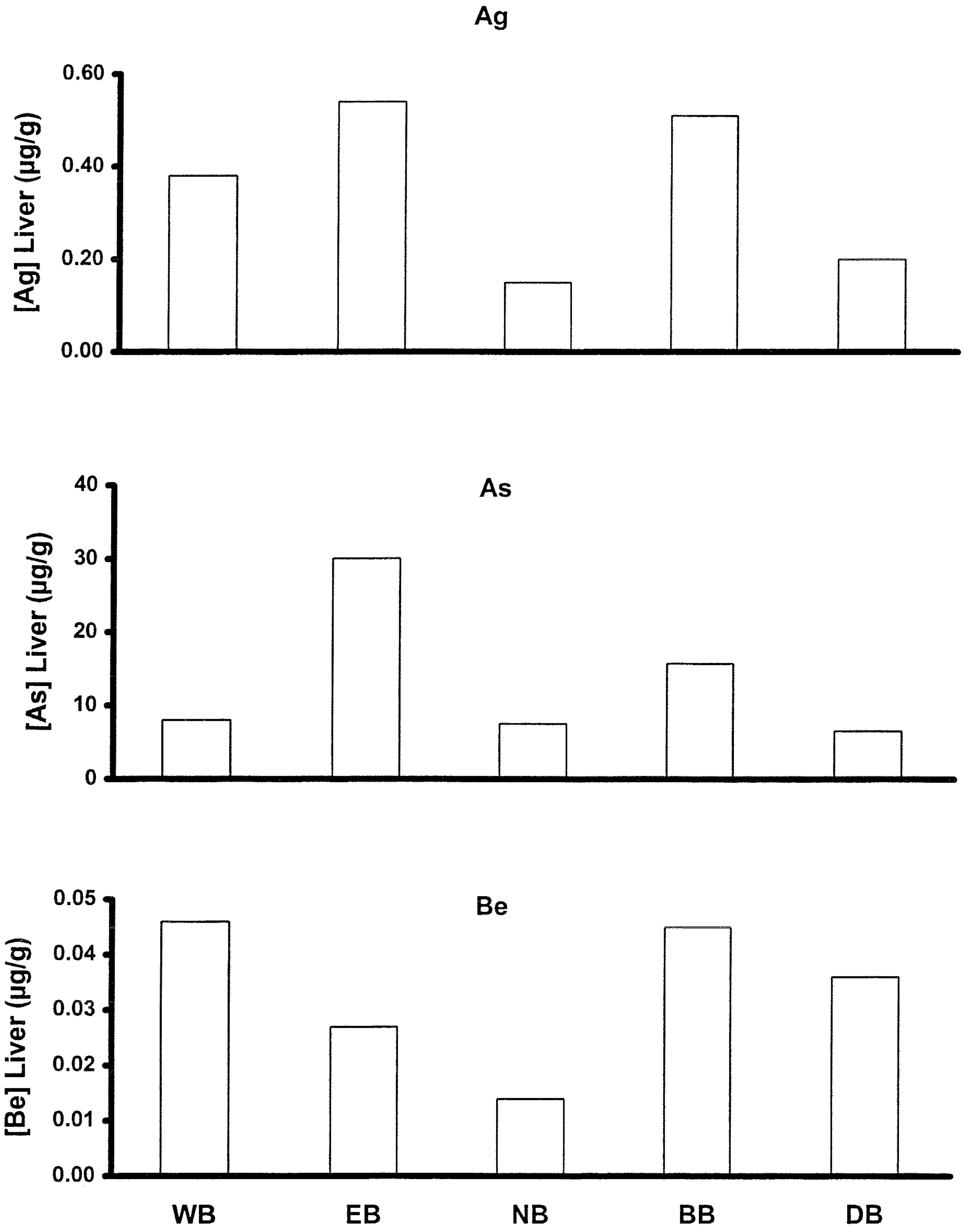

Figure 3a. Ag, As, and Be concentrations (µg/g) in flounder liver.

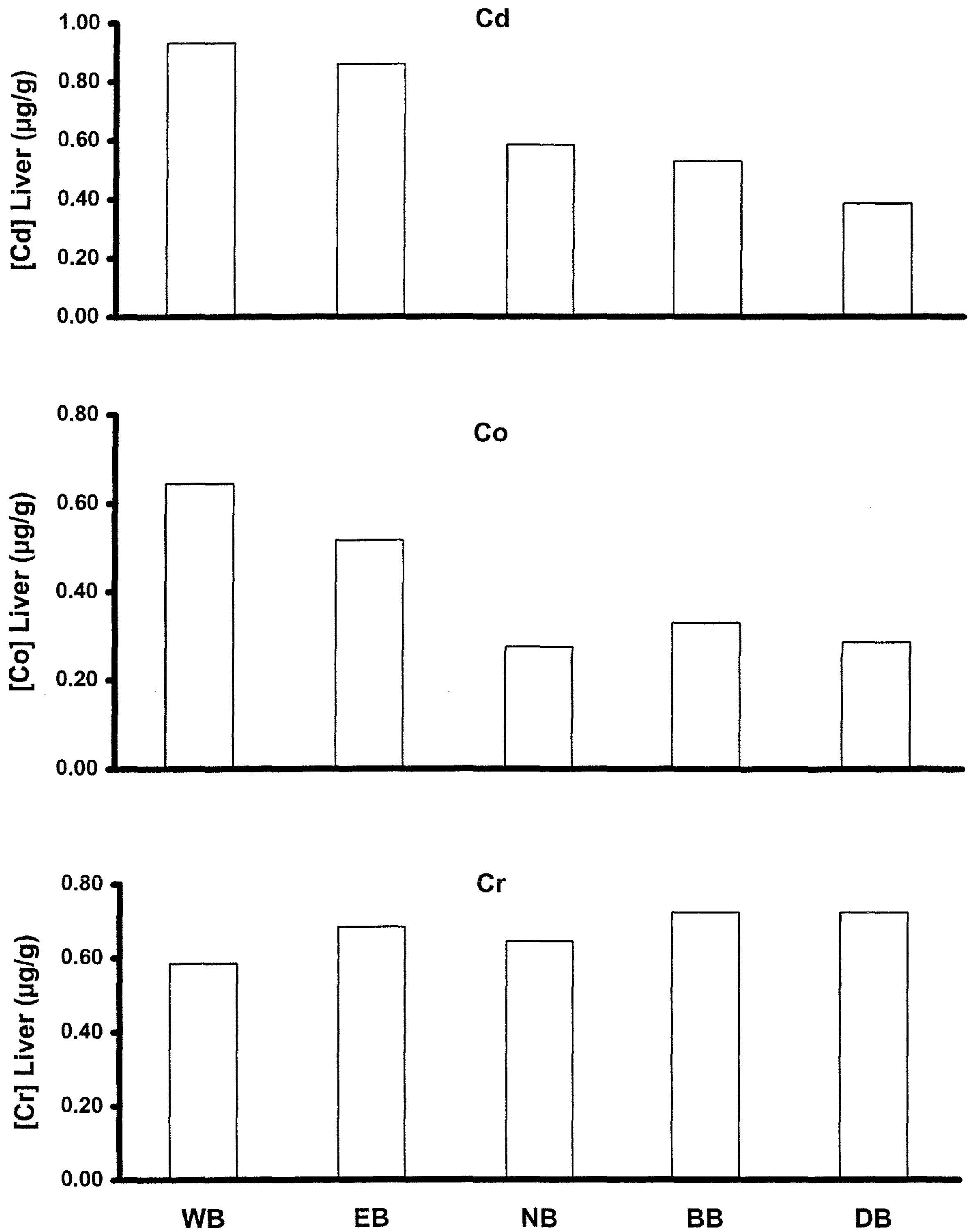

Figure 3b. Cd, Co, and Cr concentrations (µg/g) in flounder liver.

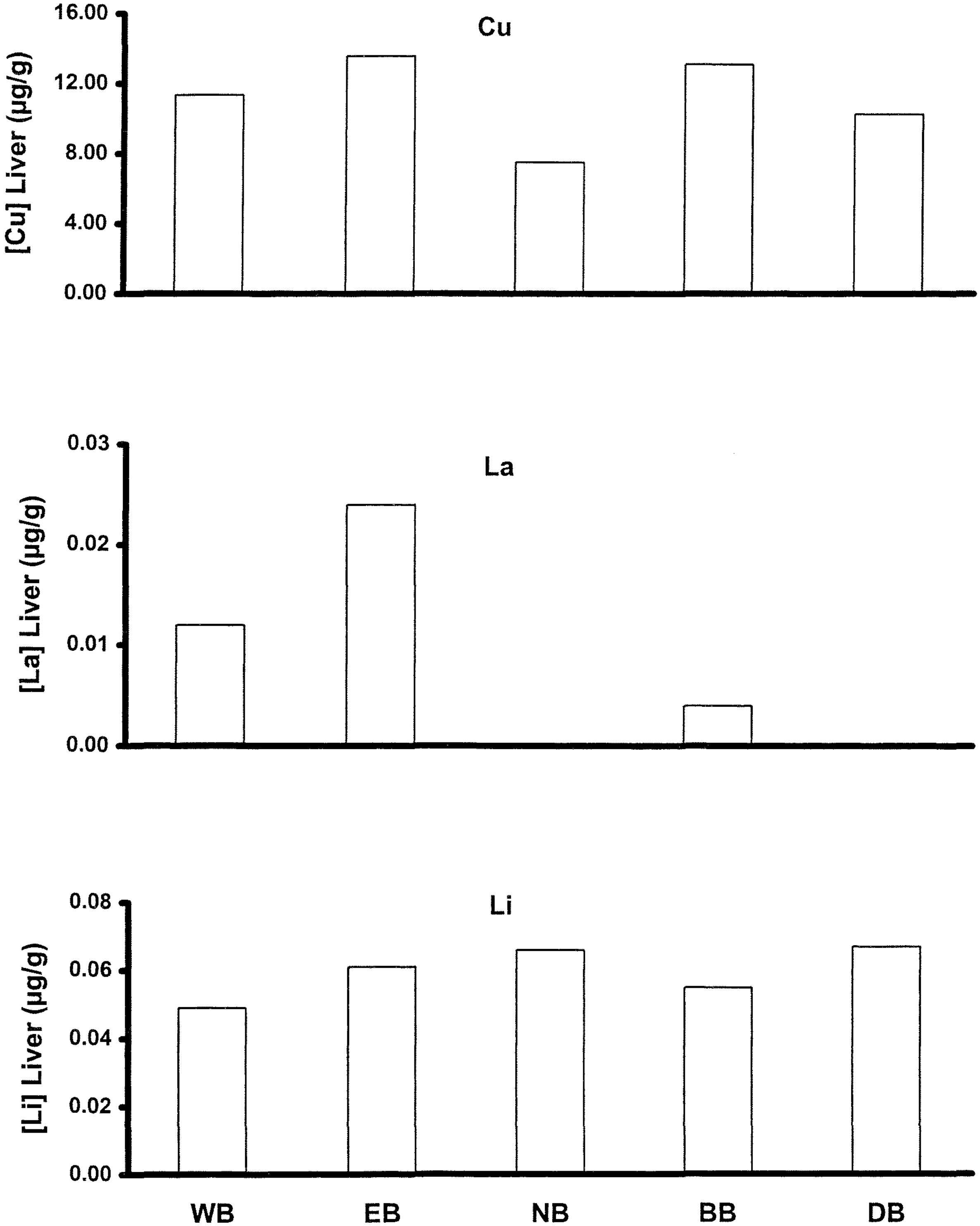

Figure 3c. Cu, La, and Li concentrations (µg/g) in flounder liver.

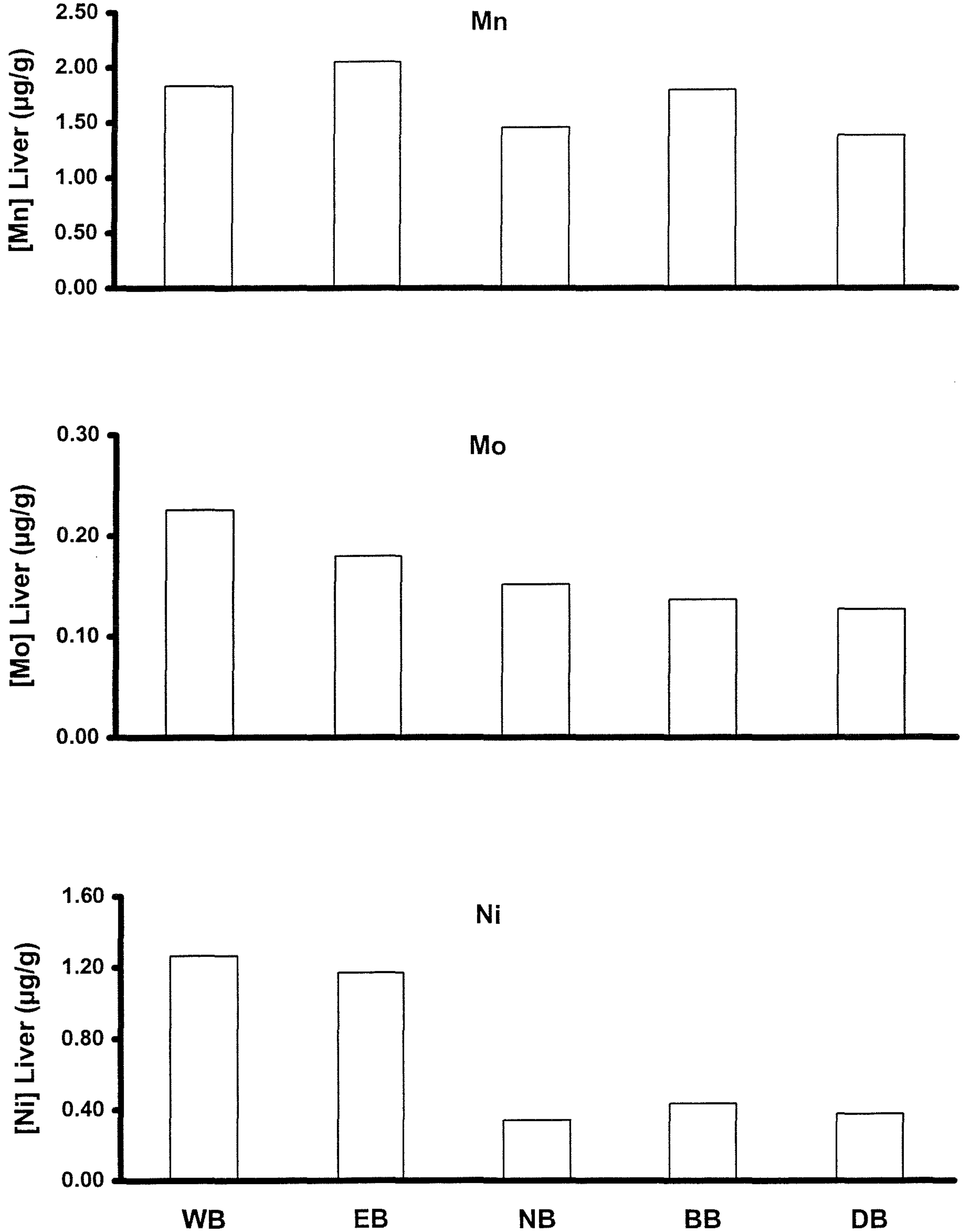

Figure 3d. Mn, Mo, and Ni concentrations (µg/g) in flounder liver.

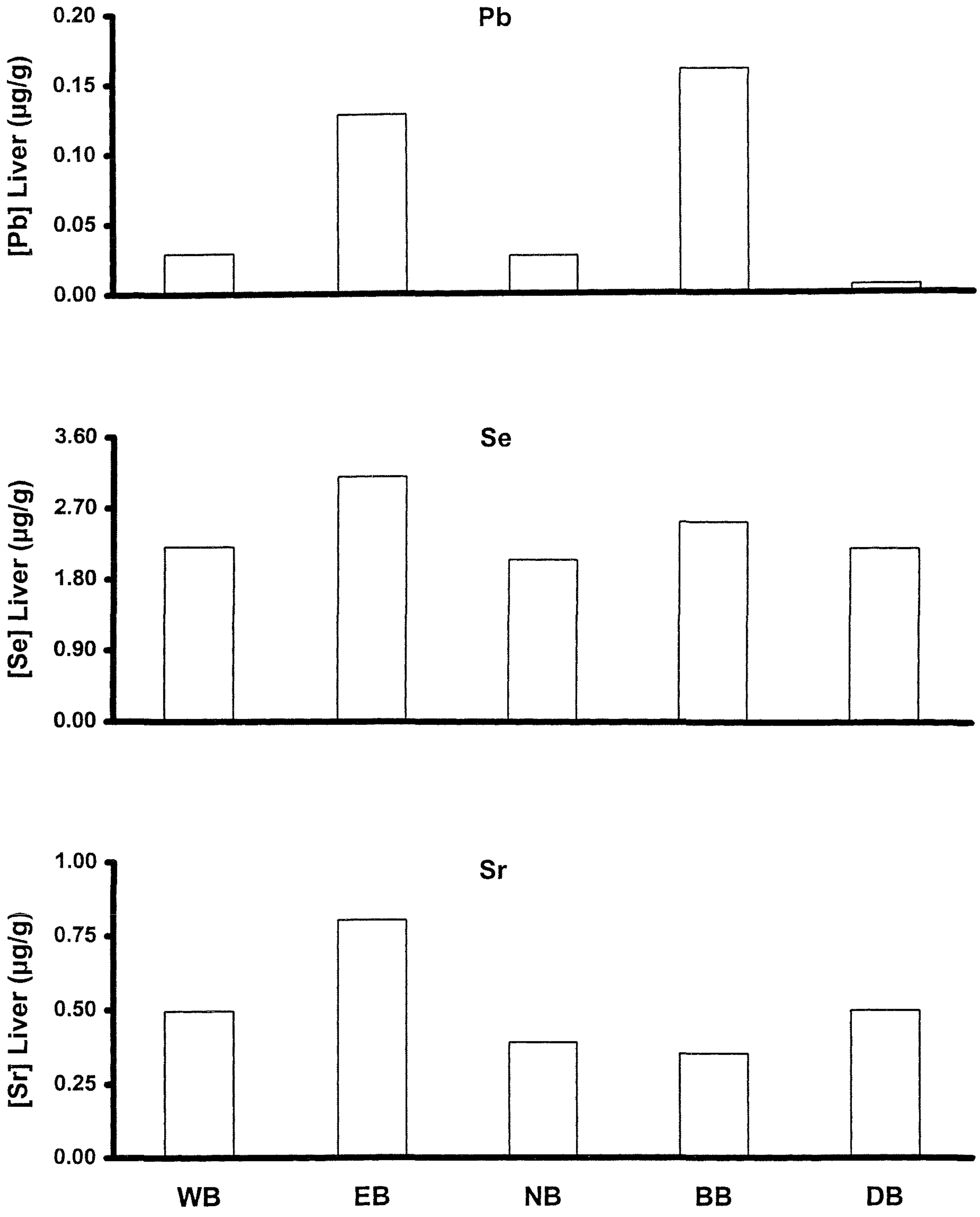

Figure 3e. Pb, Se, and Sr concentrations (µg/g) in flounder liver.

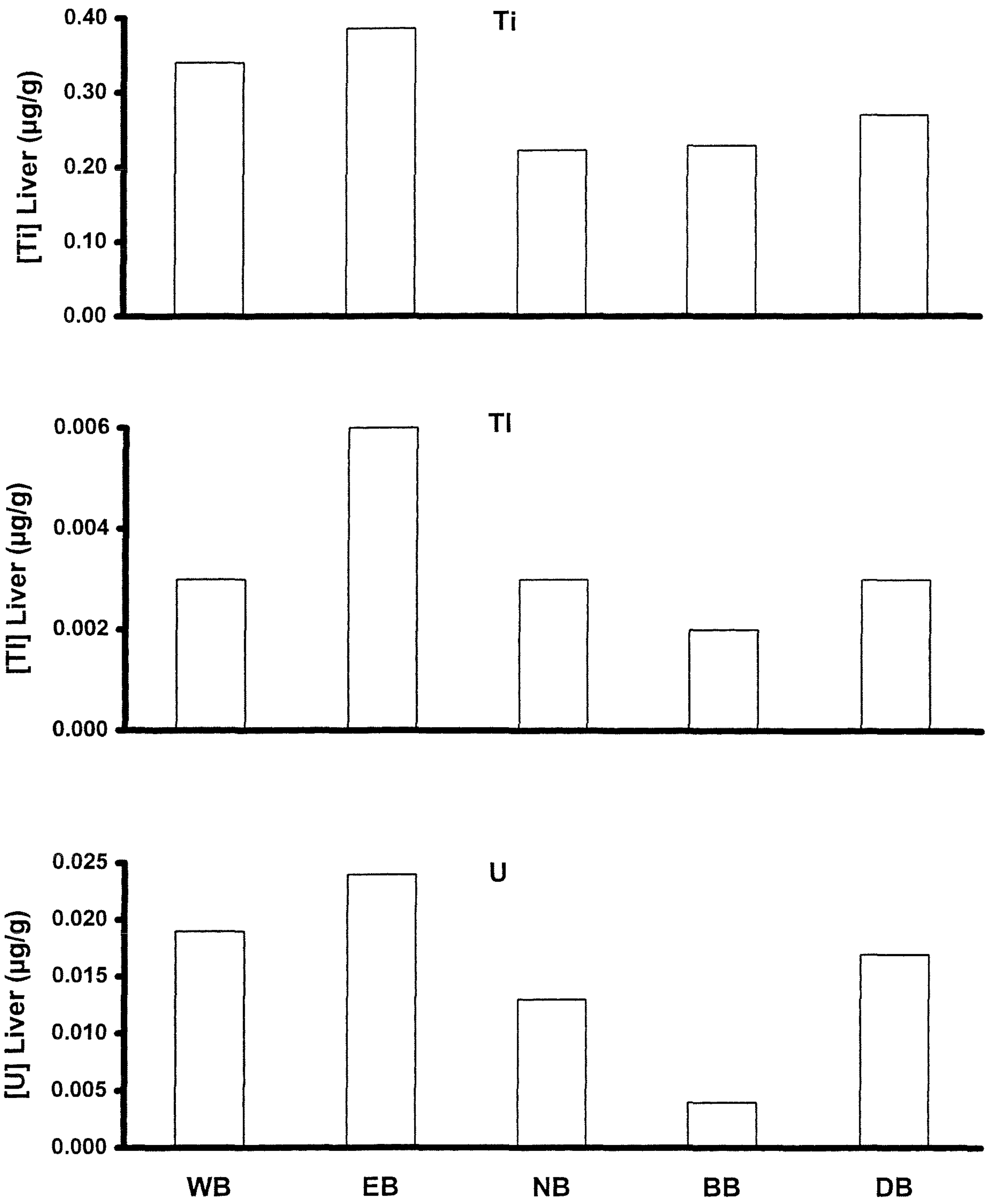

Figure 3f. Ti, Tl, and U concentrations (µg/g) in flounder liver.

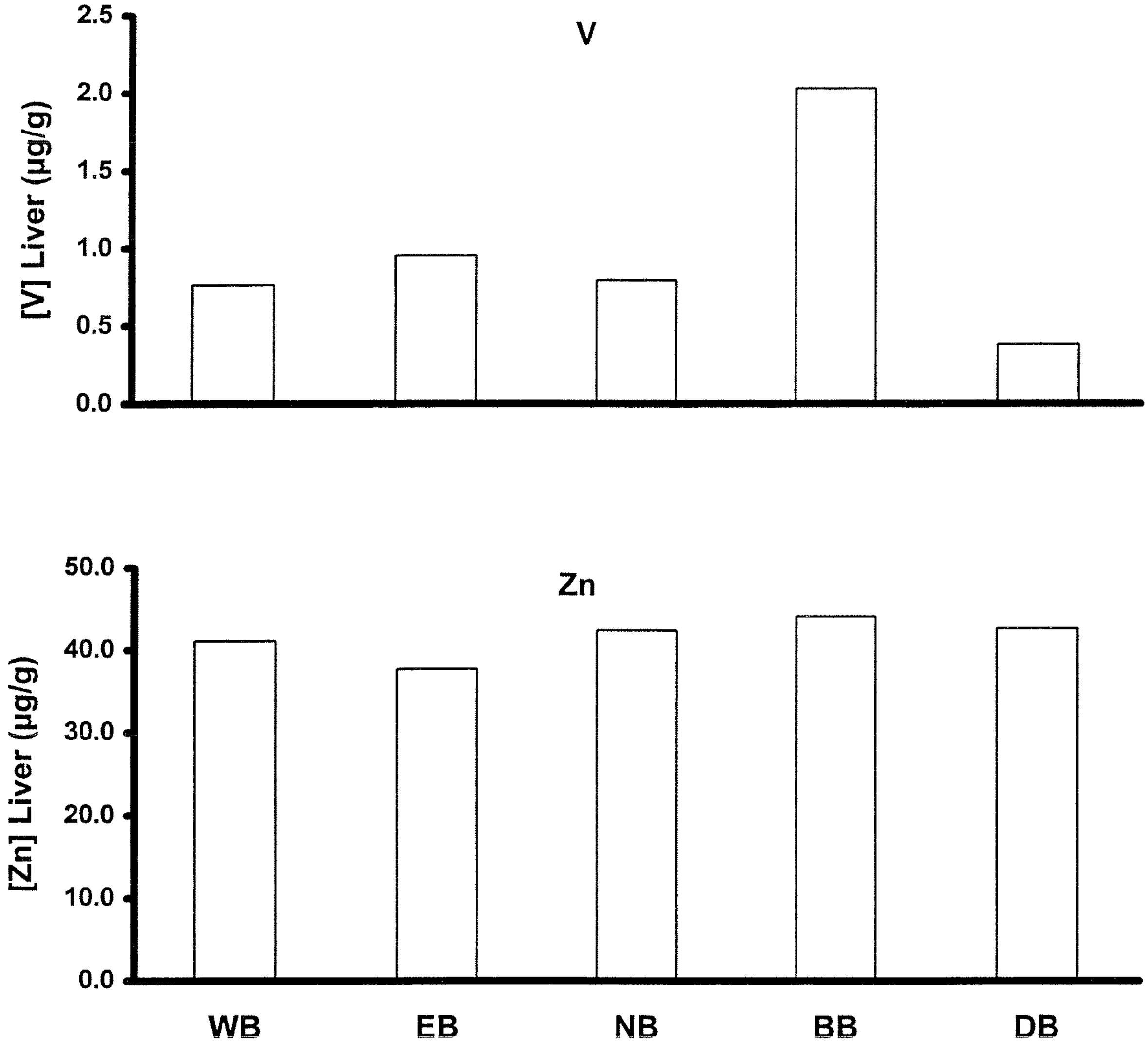

Figure 3g. V and Zn concentrations (µg/g) in flounder liver.

3.2.2. KIDNEY

Table 3. summarizes the concentrations of antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, lanthanum, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, titanium, uranium, vanadium, and zinc in flounder kidney tissue. Data is presented for Baddeck Bay (BB), Denys Basin (DB), East Bay (EB), Nyanza Bay (NB), and Whycocomagh Bay (WB).

Antimony (Sb):
not detected

Arsenic: (Fig. 4a)
Arsenic concentration ranged from 0.87-1.78µg/g. The highest concentration occurred in flounder from Baddeck Bay (1.78µg/g), followed by East Bay (1.47µg/g) samples. Whycocomagh Bay flounder had an arsenic concentration in the kidney of 1.22µg/g. Slightly lower value occurred in flounder from Denys Basin (1.00µg/g). The lowest concentration was found in flounder from Nyanza Bay (0.87µg/g).
Relative order of arsenic concentrations at each site:
BB>EB>WB>DB>NB

Beryllium: (Fig. 4a)
Beryllium ranged between 0.05-0.06µg/g in flounder kidney. Highest values were determined in flounder collected at Denys Basin (0.06µg/g) and Nyanza Bay (0.06µg/g). Whycocomagh Bay (0.05µg/g) and East Bay (0.05µg/g) flounder had similar kidney concentrations. Lowest concentration, 0.05µg/g, was in Baddeck Bay fish.
Relative order of beryllium concentrations at each site:
DB>NB>WB>EB>BB

Cadmium: (Fig. 4b)
Cadmium concentration ranged from 0.09-0.19µg/g. The highest value occurred in flounder from East Bay (0.19µg/g), followed by Whycocomagh Bay samples (0.17µg/g). Lower, but similar values were determined for flounder from Baddeck Bay (0.10µg/g) and Nyanza Bay (0.10µg/g). The lowest cadmium concentration was found in Denys Basin samples (0.09µg/g).
Relative order of cadmium concentrations at each site:
EB>WB>BB>NB>DB

Chromium: (Fig. 4b)
Kidney chromium concentrations in flounder ranged from 0.58-0.73µg/g. Denys Basin flounder had the highest concentration (0.73µg/g). Nyanza Bay flounder had a lower concentration (0.61µg/g). East Bay flounder had a kidney chromium concentration of 0.60µg/g. Baddeck Bay (0.58µg/g) and Whycocomagh Bay (0.58µg/g) had the lowest concentrations of chromium in the kidney.
Relative order of chromium concentrations at each site:
DB>NB>EB>BB>WB

Cobalt: (Fig. 4b)
Cobalt concentration ranged from 0.10-0.22µg/g. The highest concentration was found in flounder from East Bay (0.22µg/g). Nyanza Bay (0.18µg/g) and Whycocomagh Bay (0.18µg/g) flounder had similar concentrations. Lower concentrations occurred in flounder from Denys Basin (0.11µg/g) and Baddeck Bay (0.10µg/g).
Relative order of cobalt concentrations at each site:
EB>NB>WB>DB>BB

Copper: (Fig. 4c)
Copper concentration ranged from 0.67-0.85µg/g in flounder kidney. Highest concentration was found in East Bay flounder (0.85µg/g). Similar concentrations occurred in Baddeck Bay (0.78µg/g), Denys Basin (0.77µg/g) and Whycocomagh Bay flounder (0.77µg/g). Lowest concentrations were found in Nyanza Bay samples (0.67µg/g).
Relative order of copper concentrations at each site:
EB>BB>DB>WB>NB

Lanthanum (La):
not detected

Lead: (Fig. 4d)
Lead concentration ranged from 0.01-0.09µg/g. The highest lead concentration occurred in samples from Baddeck Bay (0.09µg/g). A slightly lower value was found in East Bay flounder (0.08µg/g), followed by Nyanza Bay samples which had a concentration of 0.04µg/g. The lowest concentrations were found in flounder from Denys Basin (0.01µg/g) and Whycocomagh Bay (0.01µg/g).
Relative order of lead concentrations at each site:
BB>EB>NB>DB>WB

Lithium: (Fig. 4c)
Lithium in flounder kidney ranged from 0.08-0.10µg/g. The highest concentration was found in fish from Baddeck Bay (0.10µg/g). Denys Basin flounder had a concentration of 0.10µg/g. This was similar to concentrations at Nyanza (0.09µg/g) and East Bay (0.09µg/g). Kidney lithium was lowest in flounder collected at Whycocomagh Bay: 0.08µg/g.
Relative order of lithium concentrations at each site:
BB>DB>NB>EB>WB

Manganese: (Fig. 4c)
The manganese concentration ranged between 0.82-1.34µg/g. Baddeck Bay flounder had the highest concentration of kidney manganese (1.34µg/g). East Bay had a concentration of 1.20µg/g. Whycocomagh Bay had a concentration of 1.10µg/g. Denys Basin (0.90µg/g) and Nyanza Bay (0.82µg/g) had the lowest concentrations of manganese in the kidney.
Relative order of manganese concentrations at each site:
BB>EB>WB>DB>NB

Molybdenum: (Fig. 4d)
Molybdenum in flounder kidney ranged from 0.05-0.09μg/g. The highest concentration was found in Whycocomagh Bay samples (0.09μg/g). East Bay samples had slightly lower value (0.08μg/g), followed by Denys Basin (0.07μg/g) and Nyanza Bay (0.06μg/g) samples. The lowest value occurred in Baddeck Bay flounder (0.05μg/g).
Relative order of molybdenum concentrations at each site:
WB>EB>DB>NB>BB

Nickel: (Fig. 4d)
Nickel ranged from 0.62-1.12μg/g. Highest concentration was found in flounder from East Bay (1.12μg/g). Nyanza Bay (0.76μg/g) and Denys Basin (0.74μg/g) had values in a similar range. Lowest values occurred in fish from Whycocomagh (0.67μg/g) and Baddeck (0.62μg/g) Bays.
Relative order of nickel concentrations at each site:
EB>NB>DB>WB>BB

Selenium: (Fig. 4e)
Selenium concentration in flounder kidney ranged from 2.54-4.10μg/g. The highest concentration occurred in flounder from East Bay (4.10μg/g). Baddeck Bay (2.71μg/g), Denys Basin (2.69μg/g), Whycocomagh Bay (2.57μg/g), and Nyanza Bay (2.54μg/g) had similar, lower concentrations.
Relative order of selenium concentrations at each site:
EB>BB>DB>WB>NB

Silver (Ag):
Not detected

Strontium: (Fig. 4e)
Strontium concentration ranged from 0.62-1.07μg/g. The highest concentration occurred in East Bay samples 1.07, followed by Whycocomagh Bay (0.91μg/g) and Baddeck Bay (0.89μg/g) flounder. Denys Basin fish had a concentration of 0.80μg/g. Lowest value was found in flounder from Nyanza Bay 0.62μg/g.
Relative order of strontium concentrations at each site:
EB>WB>BB>DB>NB

Thallium: (Fig. 4f)
Thallium ranged between 0.002-0.004μg/g. The highest concentration was determined in flounder from East Bay (0.004μg/g). Denys Basin samples had a concentration of 0.003. Whycocomagh, Nyanza and Baddeck all had equal thallium kidney concentrations: 0.002μg/g.
Relative order of thallium concentrations at each site:
EB>DB>WB=NB=BB

Titanium: (Fig. 4e)
Titanium ranged from 0.28-0.37μg/g. The highest concentration was determined in flounder from Baddeck Bay (0.37μg/g). East Bay (0.36μg/g) and Whycocomagh Bay (0.36μg/g) fish had

similar concentrations. Denys Basin fish had a concentration of 0.33μg/g. Nyanza Bay flounder had the lowest kidney concentration of titanium: 0.28μg/g).
Relative order of titanium concentrations at each site:
BB>EB>WB>DB>NB

Uranium: (Fig . 4f)
Uranium concentration ranged from 0.013-0.035μg/g. The highest value was determined in samples from East Bay (0.035μg/g). Slightly lower values were found in samples from Denys Basin (0.023μg/g) and Whycocomagh Bay (0.022μg/g) flounder. The lowest values were determined in samples from Nyanza Bay (0.018μg/g) and Baddeck Bay (0.013μg/g).
Relative order of uranium concentrations at each site:
EB>DB>WB>NB>BB

Vanadium: (Fig. 4g)
Vanadium in flounder kidney ranged from 0.58-1.52μg/g. The highest concentration occurred in flounder from Baddeck Bay (1.52μg/g). A lower concentration was found in Whycocomagh Bay flounder (1.24μg/g). An intermediate value was found in the kidneys of flounder from East Bay (0.83μg/g). The lowest vanadium kidney concentrations were found in flounder from Nyanza Bay (0.68μg/g) and Denys Bay (0.58μg/g).
Relative order of vanadium concentrations at each site:
BB>WB>EB>NB>DB

Zinc: (Fig. 4g)
Zinc concentration ranged from 26.2-33.1μg/g. The highest concentration occurred in flounder collected at Denys Basin (33.1μg/g). Whycocomagh Bay (33.0μg/g) and East Bay (32.4μg/g) flounder had similar concentrations. A lower concentration was determined in fish from Baddeck Bay (29.5μg/g). The lowest zinc concentration in kidney was found in samples from Nyanza Bay (26.2μg/g).
Relative order of zinc concentrations at each site:
DB>WB>EB>BB>NB

Table 3. Metal concentrations (μg/g wet weight) in kidney of flounder collected at 5 sites in the Bras d' Or Lake, Cape Breton, Nova Scotia.

Metal	BB	DB	EB	NB	WB	Range
Ag	nd	nd	nd	nd	nd	
As	1.78	1.00	1.47	0.87	1.22	0.87-1.78
Be	0.05	0.06	0.05	0.06	0.05	0.05-0.06
Cd	0.10	0.09	0.19	0.10	0.17	0.09 -0.19
Co	0.11	0.11	0.22	0.18	0.18	0.11-0.22
Cr	0.59	0.73	0.60	0.61	0.58	0.58 -0.73
Cu	0.78	0.77	0.85	0.67	0.77	0.67-0.85
La	nd	nd	nd	nd	nd	
Li	0.10	0.10	0.09	0.09	0.08	0.08-0.10
Mn	1.34	0.90	1.20	0.82	1.10	0.82 -1.34
Mo	0.05	0.07	0.08	0.06	0.09	0.05-0.09
Ni	0.62	0.74	1.12	0.76	0.67	0.62 -1.12
Pb	0.09	0.01	0.08	0.04	0.01	0.01-0.09
Sb	nd	nd	nd	nd	nd	
Se	2.71	2.69	4.10	2.54	2.57	2.54-4.10
Sr	0.89	0.80	1.07	0.62	0.91	0.62 -1.07
Ti	0.37	0.33	0.36	0.28	0.36	0.28-0.37
Tl	0.002	0.003	0.004	0.002	0.002	0.002-0.004
U	0.013	0.023	0.035	0.018	0.022	0.013-0.035
V	1.52	0.58	0.83	0.68	1.24	0.58 -1.52
Zn	29.5	33.1	32.4	26.3	33.0	26.3-33.1

Figure 4. Metal concentrations (μg/g) in flounder kidney: a) As and Be b) Cd, Co, and Cr c) Cu, Li, and Mn d) Mo, Ni and Pb e) Se, Sr and Ti f) Tl and U g) V and Zn

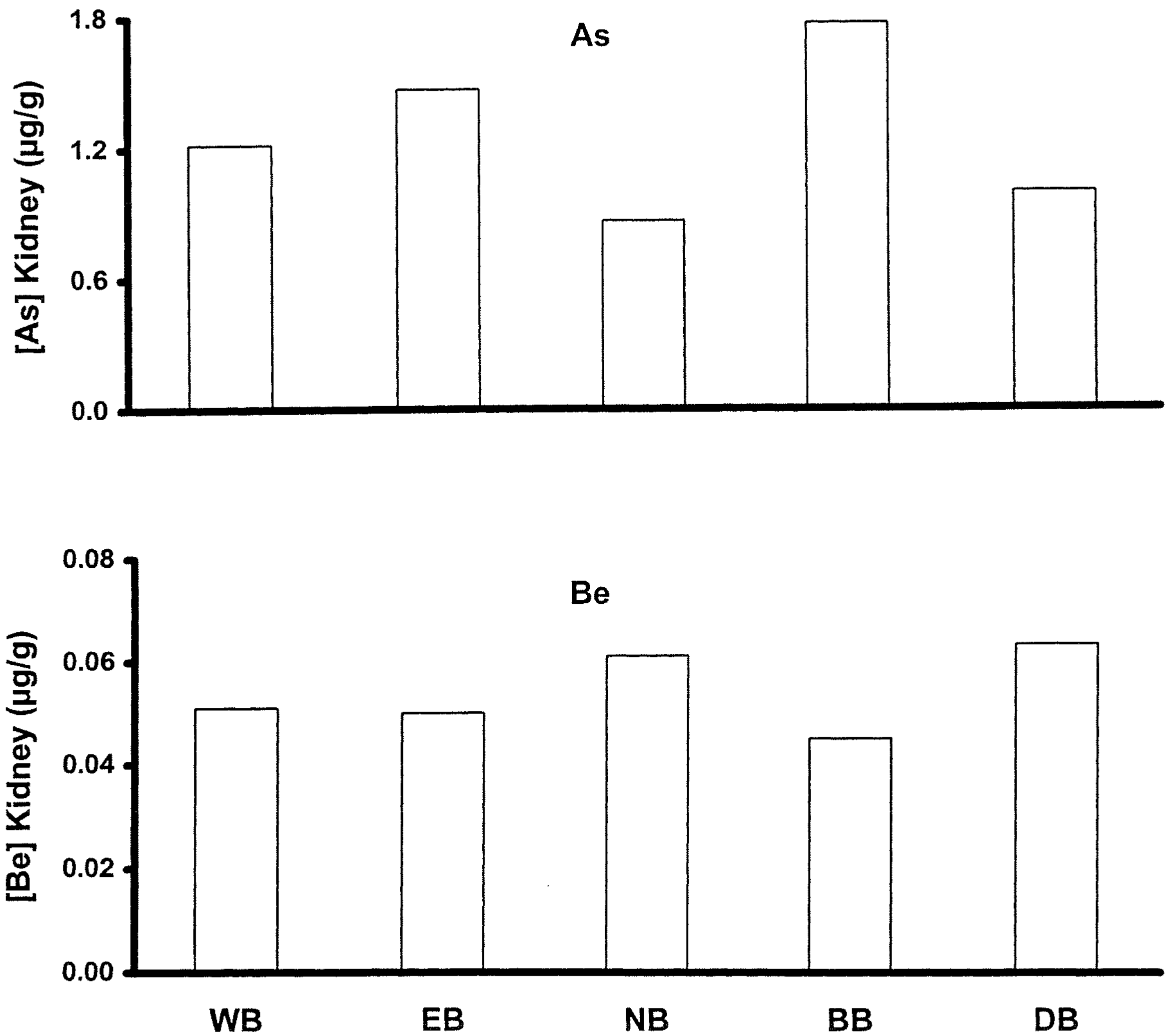

Figure 4a. As and Be concentrations (µg/g) in flounder kidney.

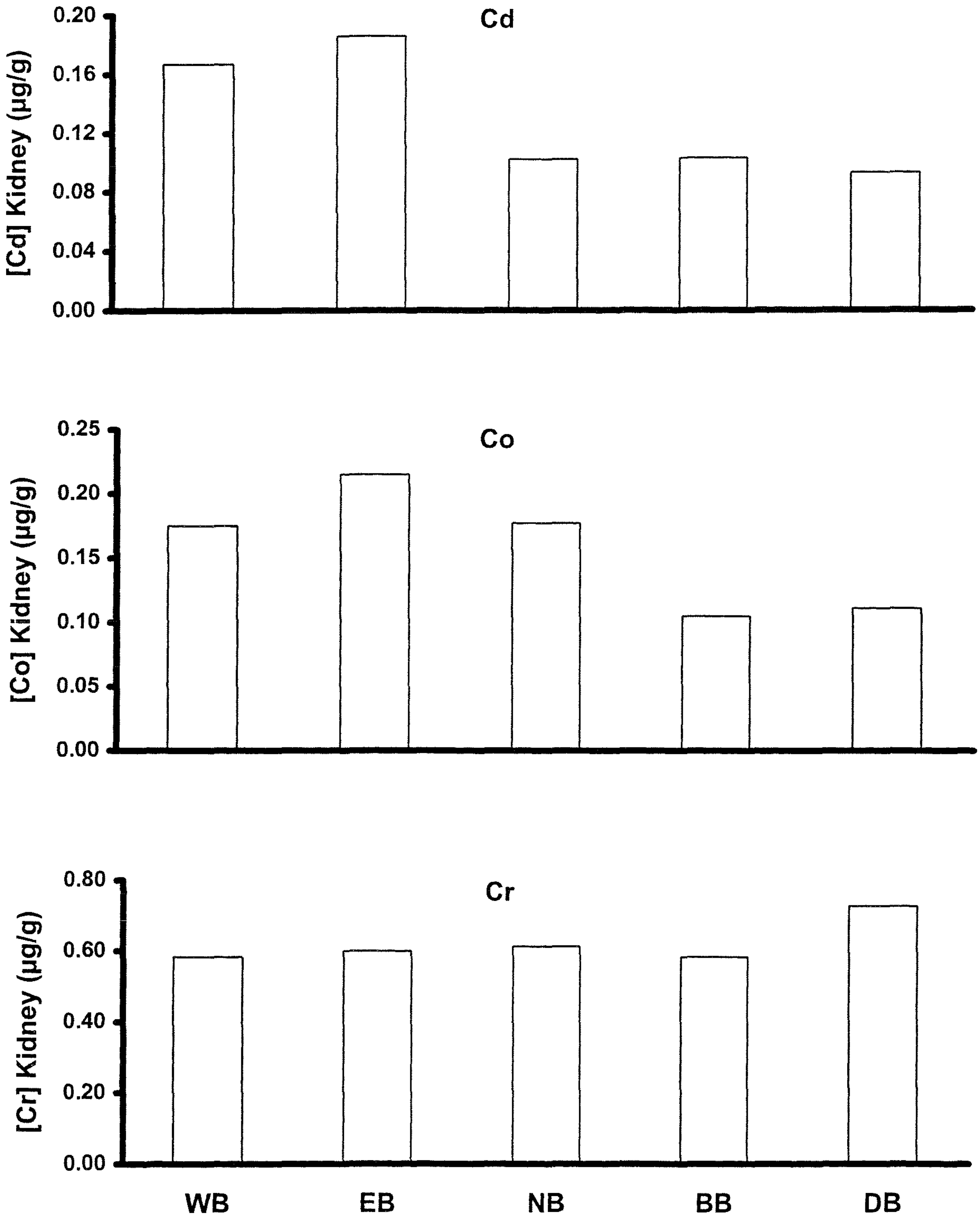

Figure 4b. Cd, Co, and Cr concentrations (µg/g) in flounder kidney.

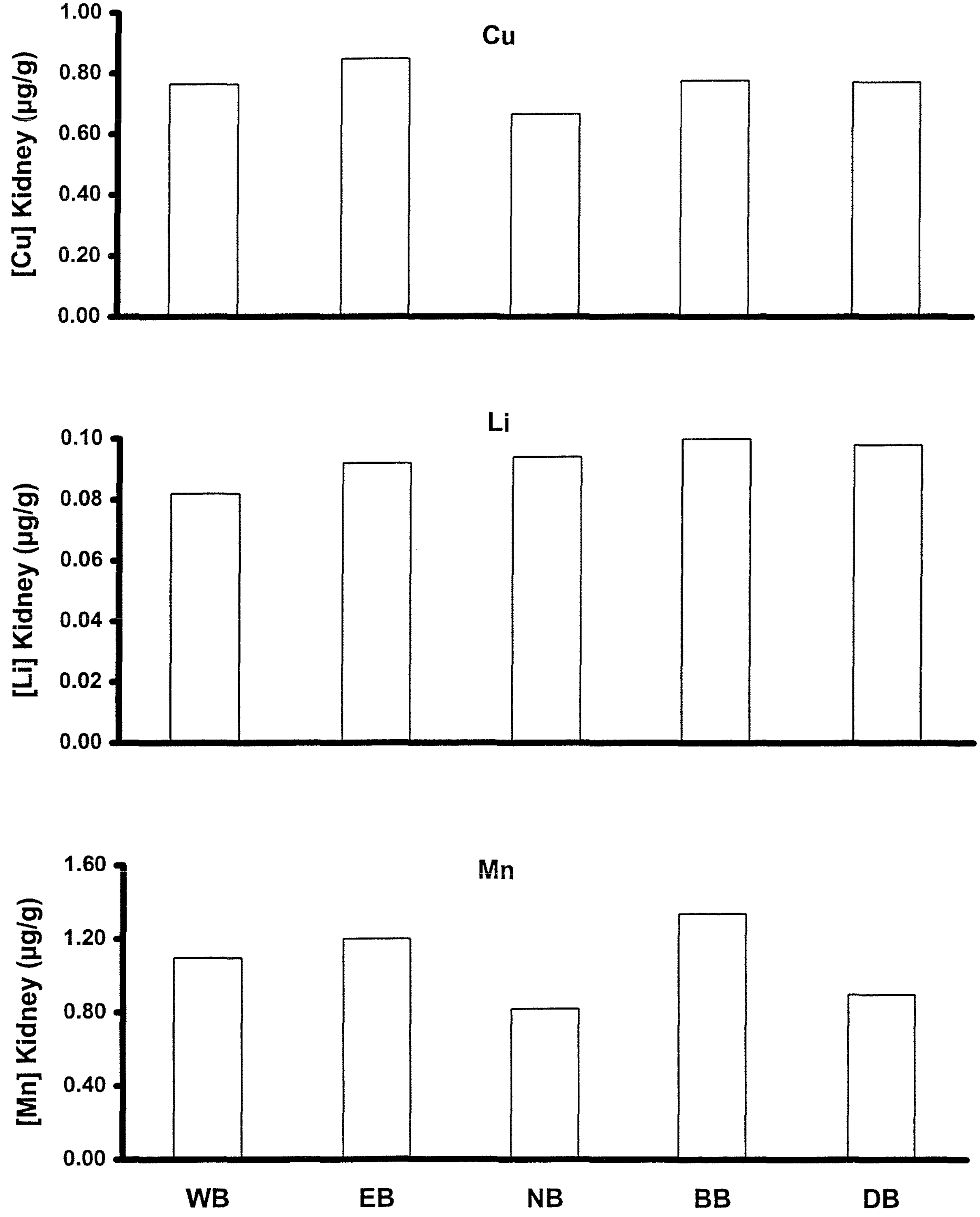

Figure 4c. Cu, Li, and Mn concentrations (µg/g) in flounder kidney.

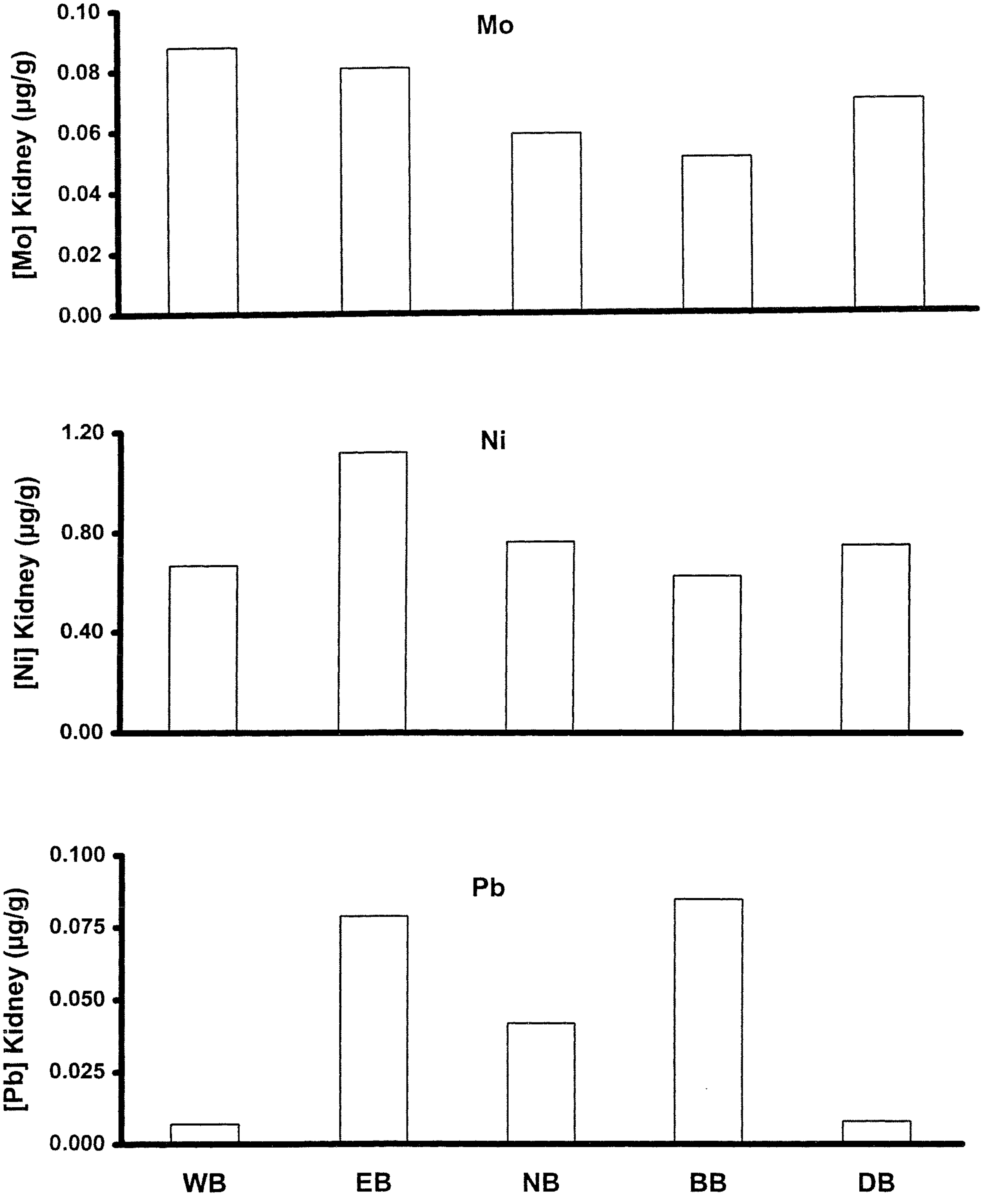

Figure 4d. Mo, Ni, and Pb concentrations (µg/g) in flounder kidney.

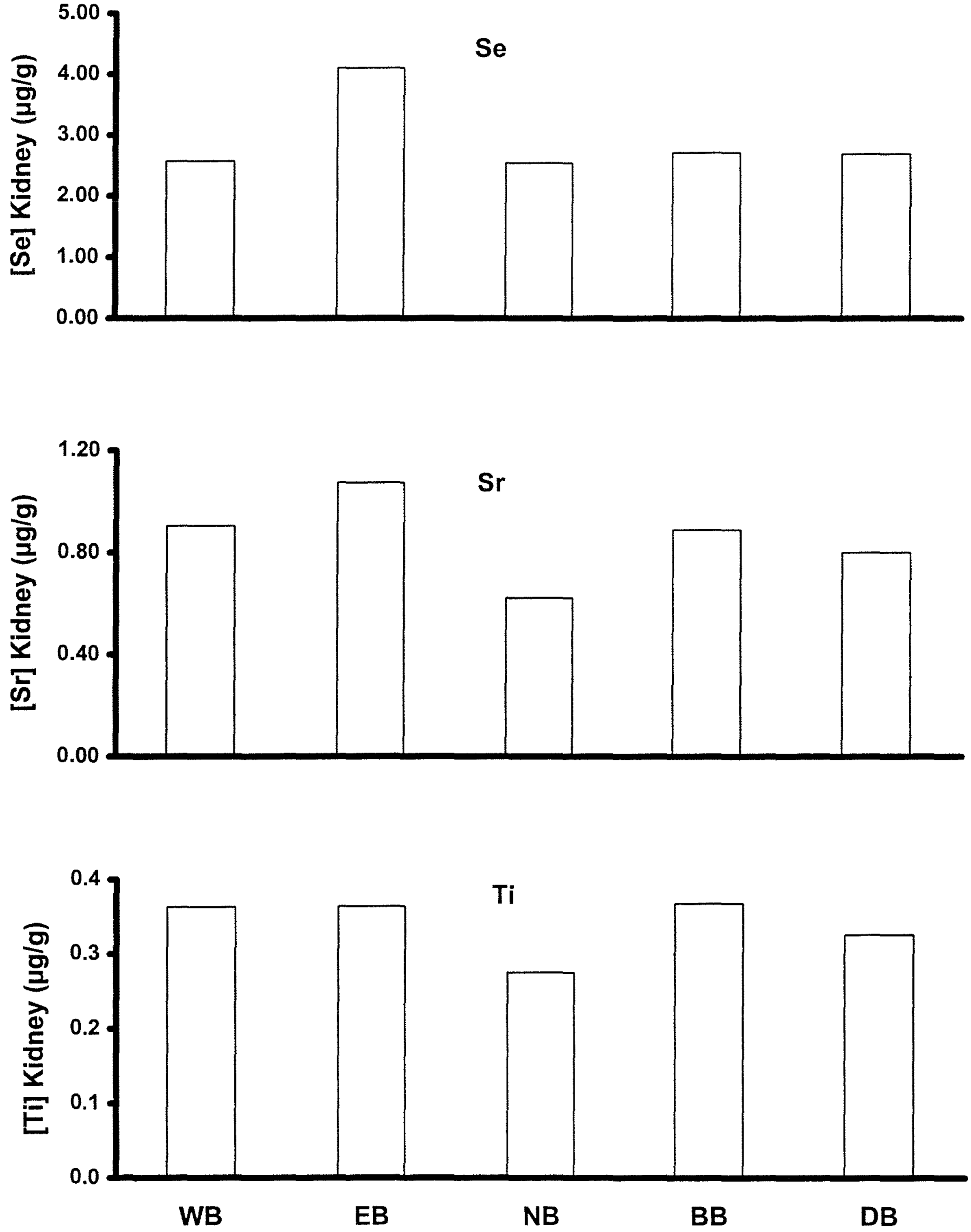

Figure 4e. Se, Sr, and Ti concentrations (µg/g) in flounder kidney.

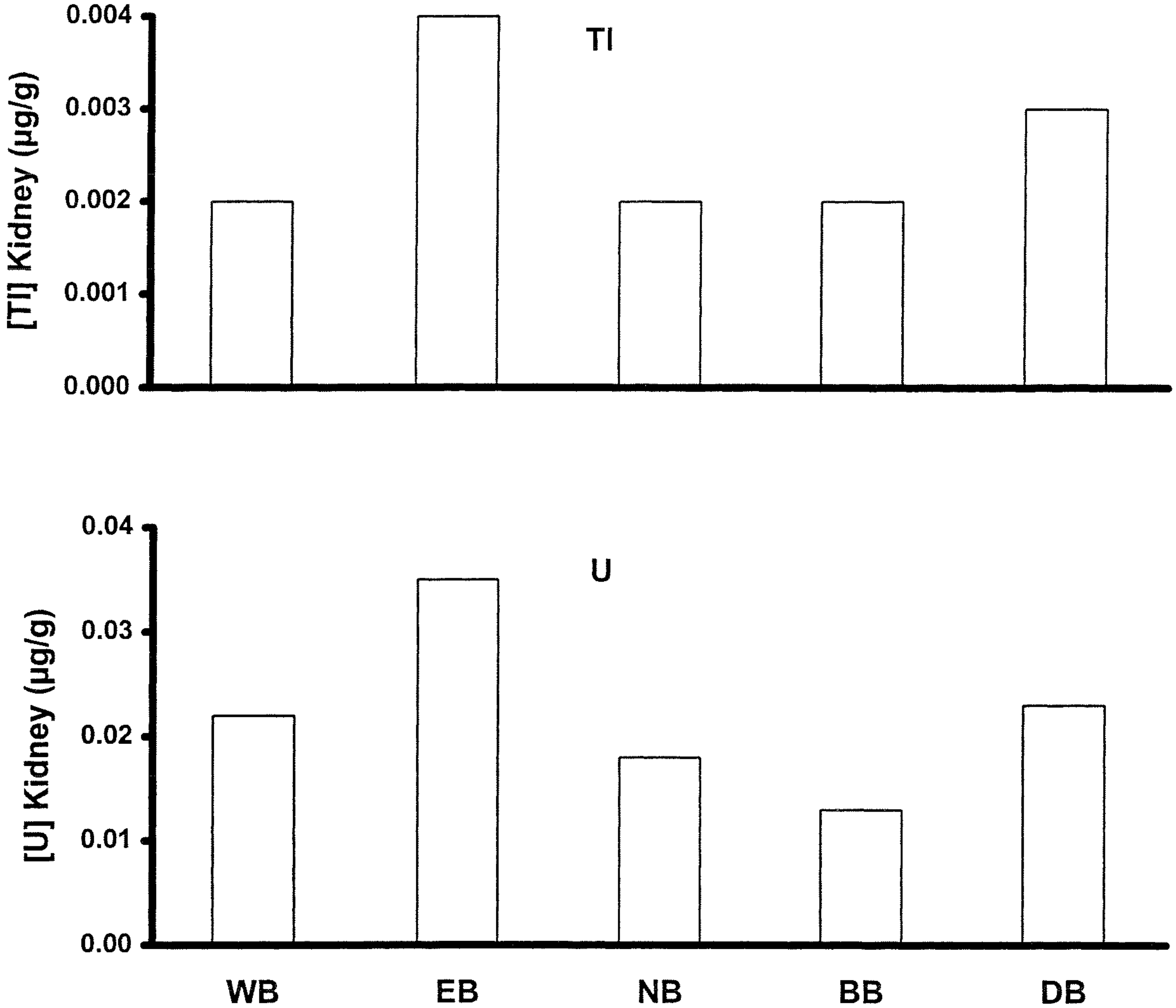

Figure 4f. Tl and U concentrations (µg/g) in flounder kidney.

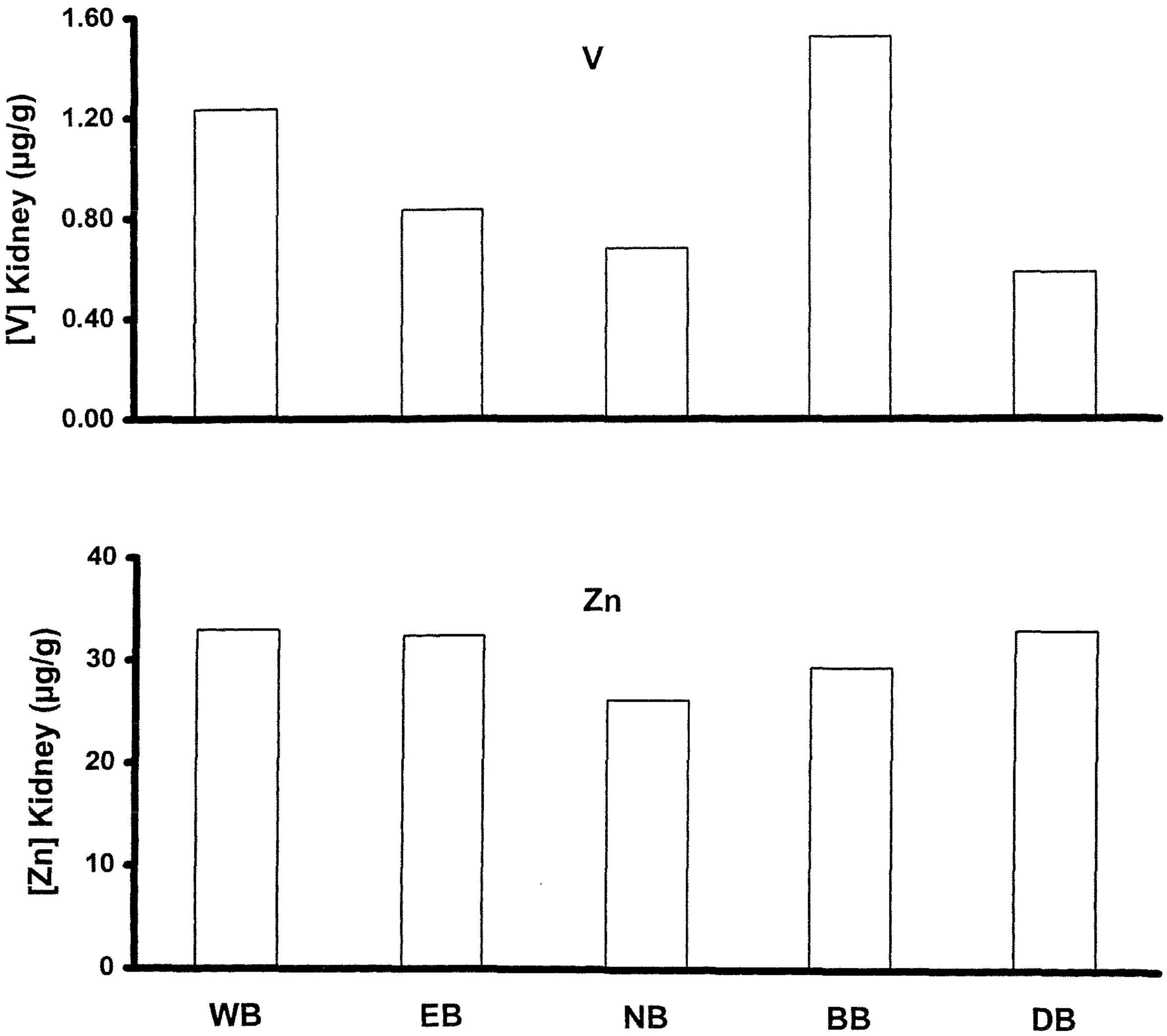

Figure 4g. V and Zn concentrations (µg/g) in flounder kidney.

3.2.3. SEDIMENT

Table 4. summarizes the concentrations of antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, lanthanum, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, titanium, uranium, vanadium, and zinc, and total organic carbon content (%) in the sediments. Data is presented for Baddeck Bay (BB), Denys Basin (DB), East Bay (EB), Nyanza Bay (NB), and Whycocomagh Bay (WB).

Antimony: (Fig. 5e)
Antimony ranged from 0.35-0.65μg/g. The highest concentration occurred in sediments collected from Whycocomagh Bay (0.65μg/g). A slightly lower concentration was found in Baddeck Bay sediments (0.63μg/g). Nyanza Bay (0.58μg/g) and East Bay sediments had similar values (0.56μg/g). The lowest concentration was found in sediments from Denys Basin (0.35μg/g).
Relative order of antimony concentrations at each site:
WB>BB>NB>EB>DB

Arsenic: (Fig. 5a)
Arsenic concentration ranged from 2.22-9.08μg/g. The highest arsenic concentration was determined in sediments collected from Whycocomagh Bay (9.08μg/g). A lower concentration was found in Baddeck Bay (8.66μg/g) and Nyanza Bay sediments (7.94μg/g). The lowest arsenic concentrations were found in East Bay (3.93μg/g) and Denys Basin sediments (2.22μg/g).
Relative order of arsenic concentrations at each site:
WB>BB>NB>EB>DB

Beryllium: (Fig. 5a)
Beryllium in sediments ranged from 0.82-2.08μg/g. The highest concentration was in sediments from Whycocomagh Bay. Nyanza Bay sediments had a concentration of 1.83μg/g. Baddeck Bay samples contained 1.41μg/g of beryllium. Denys Bay concentration was 1.34μg/g. The lowest concentration was determined in sediments from East Bay (2.08μg/g).
Relative order of beryllium concentrations at each site:
WB>NB>BB>DB>EB

Cadmium: (Fig.5b)
Cadmium concentration ranged from 0.09-0.18μg/g. The highest concentration was found in sediments from Whycocomagh Bay (0.18μg/g). East Bay (0.17μg/g) and Nyanza Bay (0.17μg/g) had similar values. Baddeck Bay was slightly lower (0.13μg/g). The lowest concentration was found in sediments from Denys Basin (0.09μg/g).
Relative order of cadmium concentrations at each site:
WB>EB>NB>BB>DB

Chromium: (Fig.5b)
Chromium in sediments ranged from 11.3-42.1μg/g. The highest concentration was in Whycocomagh Bay (42.1μg/g). Nyanza Bay had a slightly lower value (40.4μg/g). Baddeck

Bay had an intermediate value (35.67μg/g), and the concentration in East Bay was slightly lower (29.8g/g). The lowest chromium concentration was determined in sediments collected from Denys Basin (11.3μg/g).
Relative order of chromium concentrations at each site:
WB>NB>BB>EB>DB

Cobalt: (Fig.5b)
Cobalt ranged from 2.56-7.07μg/g. The highest concentration of cobalt was found in sediments from Nyanza Bay (7.07μg/g). Whycocomagh Bay (6.49μg/g) and Baddeck Bay (6.41μg/g) had similar values. East Bay had a slightly lower value (5.58μg/g). The lowest value was determined in sediments from Denys Basin (2.56μg/g).
Relative order of nickel concentrations at each site:
NB>WB>BB>EB>DB

Copper: (Fig. 5c)
Copper ranged from 4.1-14.3μg/g. The highest value was found in sediments from East Bay (14.3μg/g). Baddeck Bay had a slightly lower value (12.1μg/g), followed by Nyanza Bay (11.3μg/g). Whycocomagh Bay sediments had a concentration of 10.9μg/g. The lowest copper concentration was determined in sediments collected at Denys Basin (4.1μg/g).
Relative order of copper concentrations at each site:
EB>BB>NB>WB>DB

Lanthanum: (Fig.5c)
Lanthanum concentration ranged from 0.57-0.85μg/g. Highest lanthanum concentration was found in East Bay sediments (0.85μg/g). Baddeck Bay had a slightly lower value (0.82μg/g). An intermediate value was determined in sediments from Nyanza Bay (0.76μg/g). Whycocomagh Bay samples had a concentration of 0.62μg/g. The lowest lanthanum concentration in the sediments was found in Denys Bay (0.57μg/g).
Relative order of lanthanum concentrations at each site:
EB>BB>NB>WB>DB

Lead: (Fig.5e)
Lead concentration in the sediments ranged from 3.51-8.86μg/g. The highest concentration was found in sediments from Baddeck Bay (8.86μg/g). Denys Basin sediments had a value of 5.42μg/g. East Bay (4.77μg/g) and Whycocomagh (4.52μg/g) sediments were slightly lower. The lowest concentration of lead in the sediments was found in Nyanza Bay samples (3.51μg/g).
Relative order of lead concentrations at each site:
BB>DB>EB>WB>NB

Lithium: (Fig.5c)
Lithium in sediments ranged from 11.5-47.3μg/g. The highest concentration was found in sediments collected at Whycocomagh Bay (47.3μg/g). Nyanza Bay sediments had a concentration of 45.3μg/g. Baddeck Bay had 31.0μg/g. Denys Basin sediments had a slightly lower concentration (28.1μg/g). The lowest sediment concentration was found in the East Bay sample (11.5μg/g).

Relative order of lithium concentrations at each site:
WB>NB>BB>DB>EB

Manganese: (Fig. 5d)
Manganese concentration ranged from 95-155µg/g. The highest concentration was determined in sediments collected at Baddeck Bay (155µg/g), followed by East Bay (152µg/g) and Nyanza Bay (152µg/g) samples. Whycocomagh Bay samples were slightly lower (127µg/g). The lowest manganese concentrations were found in sediments collected at Denys Bay (95g/g).
Relative order of manganese concentrations at each site:
BB>EB>NB>WB>DB

Molybdenum: (Fig.5d)
Molybdenum concentration ranged from 0.34-2.64µg/g. The highest concentration was found in sediments from Whycocomagh Bay (2.64µg/g). A slightly lower concentration was found in samples from Nyanza Bay (2.39µg/g) and Baddeck Bay (2.12µg/g). East Bay samples had a molybdenum concentration of (1.04µg/g). The lowest molybdenum concentration was found in sediments from Denys Basin (0.34µg/g).
Relative order of molybdenum concentrations at each site:
WB>NB>BB>EB>DB

Nickel: (Fig. 5d)
Nickel ranged from 12.7-110µg/g. The highest concentration was found in Baddeck Bay samples (110µg/g). Whycocomagh Bay had a lower concentration (96.7µg/g). Concentration at Nyanza Bay was 74.0µg/g. East Bay samples were slightly lower (69.6µg/g). The lowest concentration was determined in samples from Denys Basin (12.7µg/g).
Relative order of nickel concentrations at each site:
BB>WB>NB>EB>DB

Selenium: (Fig.5e)
Selenium concentration ranged from undetectable levels to 7.92µg/g. 7.92µg/g selenium were found in Baddeck Bay sediments. A slightly lower concentration was determined in sediments from East Bay (5.90µg/g) and Denys Basin (4.27µg/g). Whycocomagh Bay contained 3.14µg/g and Nyanza Bay, 1.82µg/g.
Relative order of selenium concentrations at each site:
BB>EB>DB>NB>WB

Silver: (Fig. 5a)
The silver concentration ranged from undetectable to 0.087µg/g. The highest concentration was found in Nyanza Bay sediments (0.087µg/g). Whycocomagh Bay sediments had 0.077µg/g and Baddeck Bay had similar concentrations (0.075µg/g). East Bay silver was 0.058µg/g. Silver was not detected in Denys Basin sediments.
Relative order of silver concentrations at each site:
NB>WB>BB>EB>DB

Strontium: (Fig.5f)
Strontium concentration ranged from 8.37-26.1μg/g. The highest concentration was in sediments from Denys Basin (26.1μg/g), followed by East Bay which had about half that concentration (13.1μg/g). A slightly lower concentration was found in sediments from Baddeck Bay (11.5μg/g). The lowest strontium concentrations occurred in sediments from Nyanza Bay (9.55μg/g) and Whycocomagh Bay (8.37μg/g).
Relative order of strontium concentrations at each site:
DB>EB>BB>NB>WB

Thallium: (Fig.5f)
Thallium ranged from 0.16-0.32μg/g. The highest value was found in Baddeck Bay and Whycocomagh Bay samples (0.32μg/g). Nyanza Bay samples had a slightly lower concentration (0.31μg/g). East Bay samples had a concentration of 0.26μg/g. The lowest concentration was found in Denys Basin samples (0.16μg/g).
Relative order of thallium concentrations at each site:
BB>WB>NB>EB>DB

Titanium: (Fig.5f)
Titanium ranged from 789-1750μg/g. The highest concentration was in Nyanza Bay samples (1750μg/g). East Bay sediments had a slightly lower concentration (1722μg/g). Whycocomagh Bay samples had a titanium concentration of 1615μg/g, followed by Baddeck Bay (1351μg/g). The lowest concentration was determined in sediments collected at Denys Basin (789μg/g).
Relative order of titanium concentrations at each site:
NB>EB>WB>BB>DB

Uranium: (Fig.5g)
Uranium concentrations ranged from 1.03-2.80μg/g. The highest value was found in sediments collected at Nyanza Bay (2.80μg/g). Slightly lower values were found in sediments from East Bay (2.37μg/g), Baddeck Bay (2.22μg/g) and Whycocomagh Bay (2.20μg/g). The lowest sediment concentration of uranium was determined in sediments from Denys Basin (1.03μg/g).
Relative order of uranium concentrations at each site:
NB>EB>BB>WB>DB

Vanadium: (Fig. 5g)
Vanadium concentration ranged from 20.4-62.9μg/g. Nyanza Bay sediments had the highest concentration (62.9μg/g), followed by Baddeck Bay (60.4μg/g) and Whycocomagh Bay sediments (58.7μg/g). East Bay had a lower concentration (54.7μg/g). Denys Bay had the lowest value (20.4μg/g).
Relative order of vanadium concentrations at each site:
NB>BB>WB>EB>DB

Zinc: (Fig. 5g)
Zinc concentration ranged from 21.8-57.8μg/g. The highest concentration was found in sediments from Whycocomagh Bay (57.8μg/g). Nyanza Bay sediments had a concentration of

57.3μg/g, followed by Baddeck Bay with a concentration of 50.2μg/g. East Bay had a sediment zinc value of 47.7μg/g. Denys Basin had the lowest zinc concentration (21.8μg/g).
Relative order of zinc concentrations at each site:
WB>NB>BB>EB>DB

Table 4 shows that the organic carbon content in sediments from the 5 sites in the Bras d'Or Lake, in descending order, are as follows: Whycocomagh Bay (6.6%), Nyanza Bay (6.2%), Baddeck Bay (4.9%), East Bay (3.4%), and Denys Basin (2.0%).

Table 4. Metal concentrations (μg/g dry weight), and organic carbon content (%), in sediments collected at 5 sites in the Bras d' Or Lake, Cape Breton, Nova Scotia.

Metal	BB	DB	EB	NB	WB	Range
Ag	0.075	nd	0.058	0.087	0.077	0-0.087
As	8.66	2.22	3.93	7.94	9.08	2.22-9.08
Be	1.41	0.82	1.35	1.83	2.08	0.82-2.08
Cd	0.13	0.09	0.17	0.17	0.18	0.09-0.18
Co	6.41	2.56	5.58	7.07	6.49	2.56-7.07
Cr	35.7	11.3	29.8	40.4	42.1	11.3-42.1
Cu	12.1	4.1	14.3	11.3	10.9	4.1-14.3
La	0.82	0.57	0.85	0.76	0.62	0.57-0.85
Li	28.1	11.5	31.0	45.3	47.3	11.5-47.3
Mn	155	95	152	152	127	95-155
Mo	2.12	0.34	1.04	2.39	2.64	0.34-2.64
Ni	110	12.7	69.6	96.7	74.0	12.7-110
Pb	8.86	5.43	4.77	3.51	4.52	3.51-8.86
Sb	0.63	0.35	0.56	0.58	0.65	0.35-0.65
Se	7.92	4.27	5.90	1.82	3.14	1.82-7.92
Sr	11.5	26.1	13.1	9.55	8.37	8.37-26.1
Ti	1351	789	1722	1750	1615	789-1750
Tl	0.32	0.16	0.26	0.31	0.32	0.16-0.32
U	2.22	1.03	2.37	2.80	2.20	1.03-2.80
V	60.4	20.4	54.7	62.9	58.7	20.4-62.9
Zn	50.2	21.8	47.7	57.3	57.8	21.8-57.8
	BB	DB	EB	NB	WB	Range
Organic carbon (%)	4.9	2.0	3.4	6.2	6.6	2.0-6.6%

Figure 5. Metal concentrations (μg/g) in flounder sediments: a) Ag, As and Be b) Cd, Co and Cr c) Cu, La and Li d) Mn, Mo and Ni e) Pb, Sb and Se f) Sr, Ti and Tl g) U, V and Zn

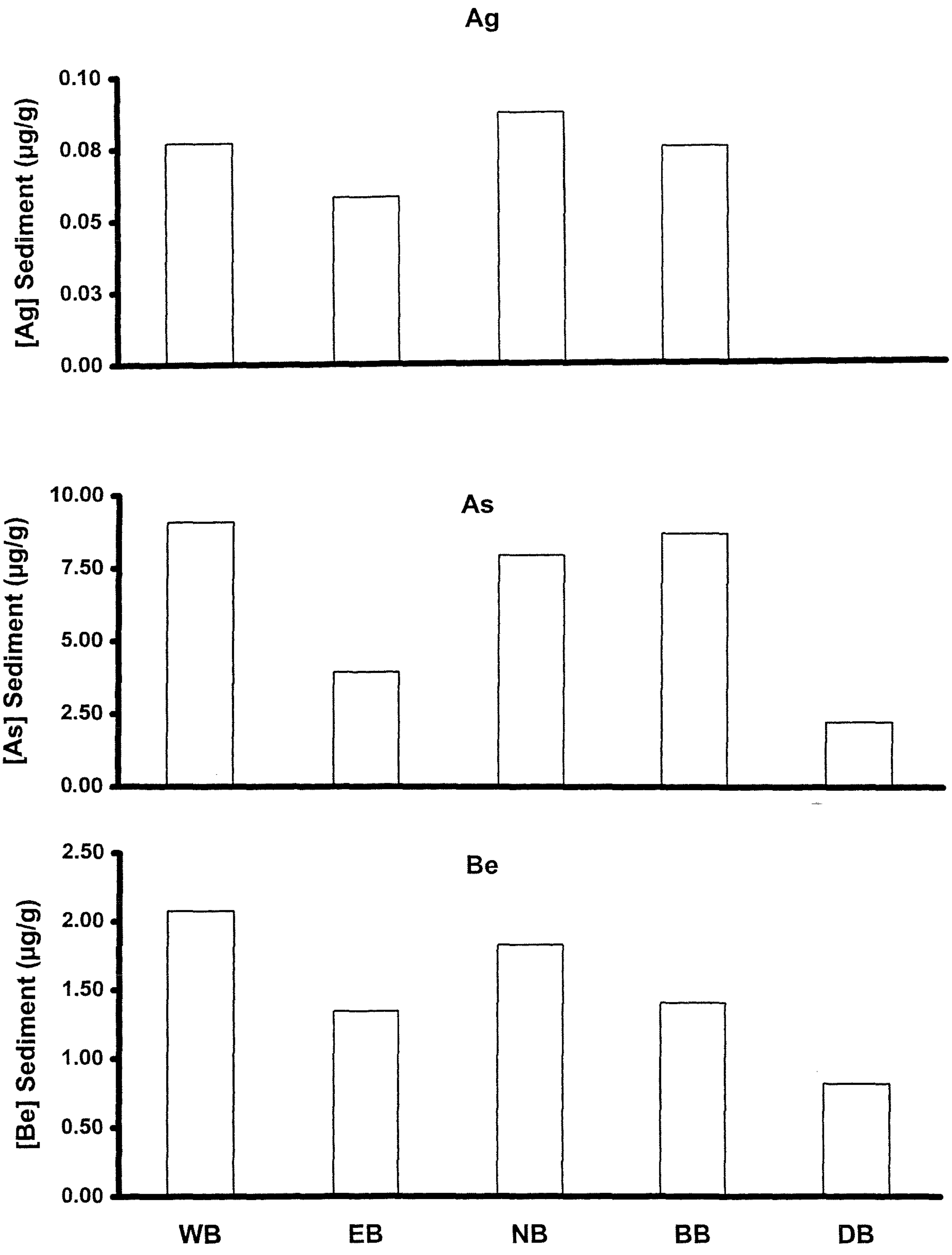

Figure 5a. Ag, As, and Be concentrations (µg/g) in Bras d' Or Lake sediment.

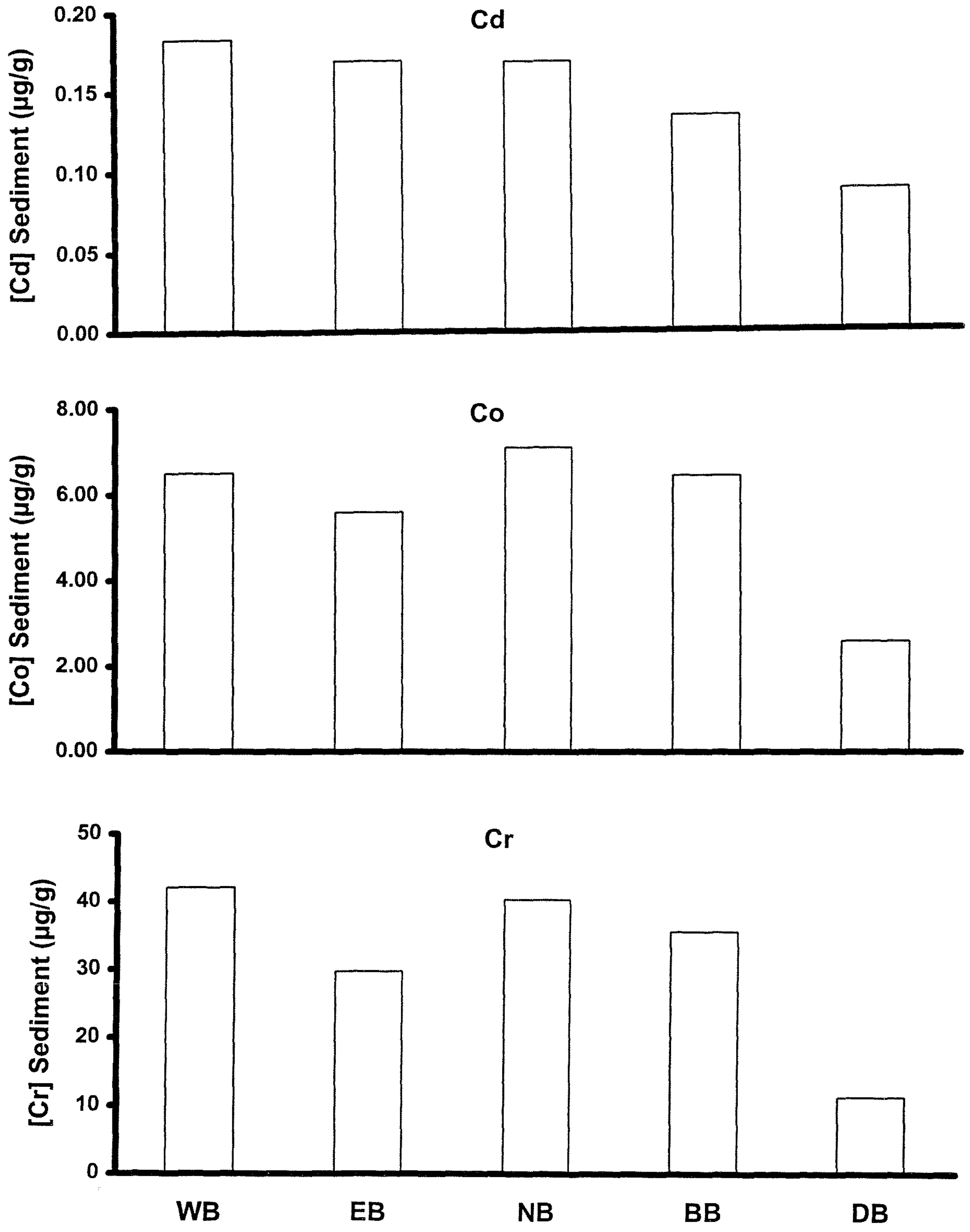

Figure 5b. Cd, Co, and Cr concentrations (µg/g) in Bras d' Or Lake sediment.

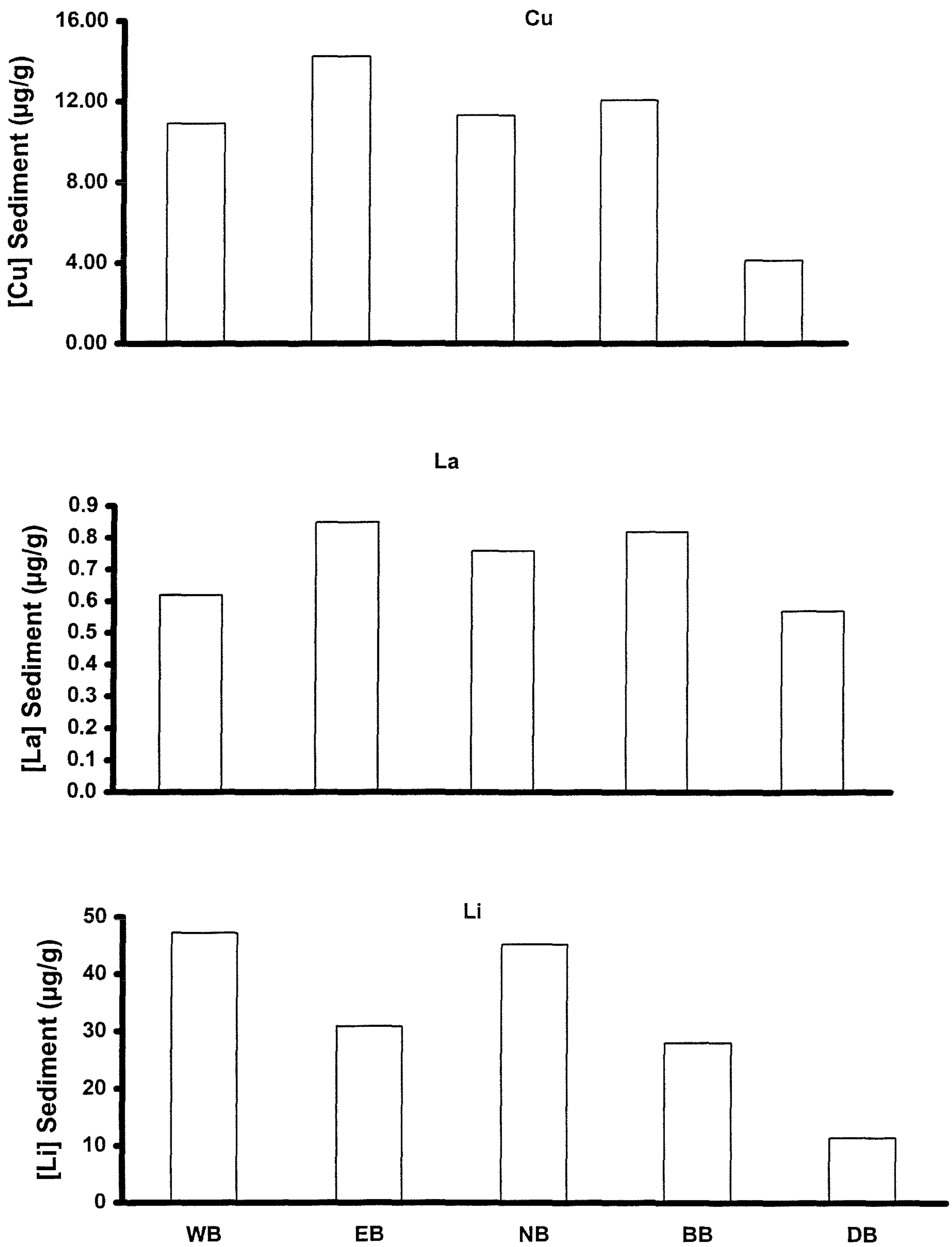

Figure 5c. Cu, La, and Li concentrations (µg/g) in Bras d' Or Lake sediment.

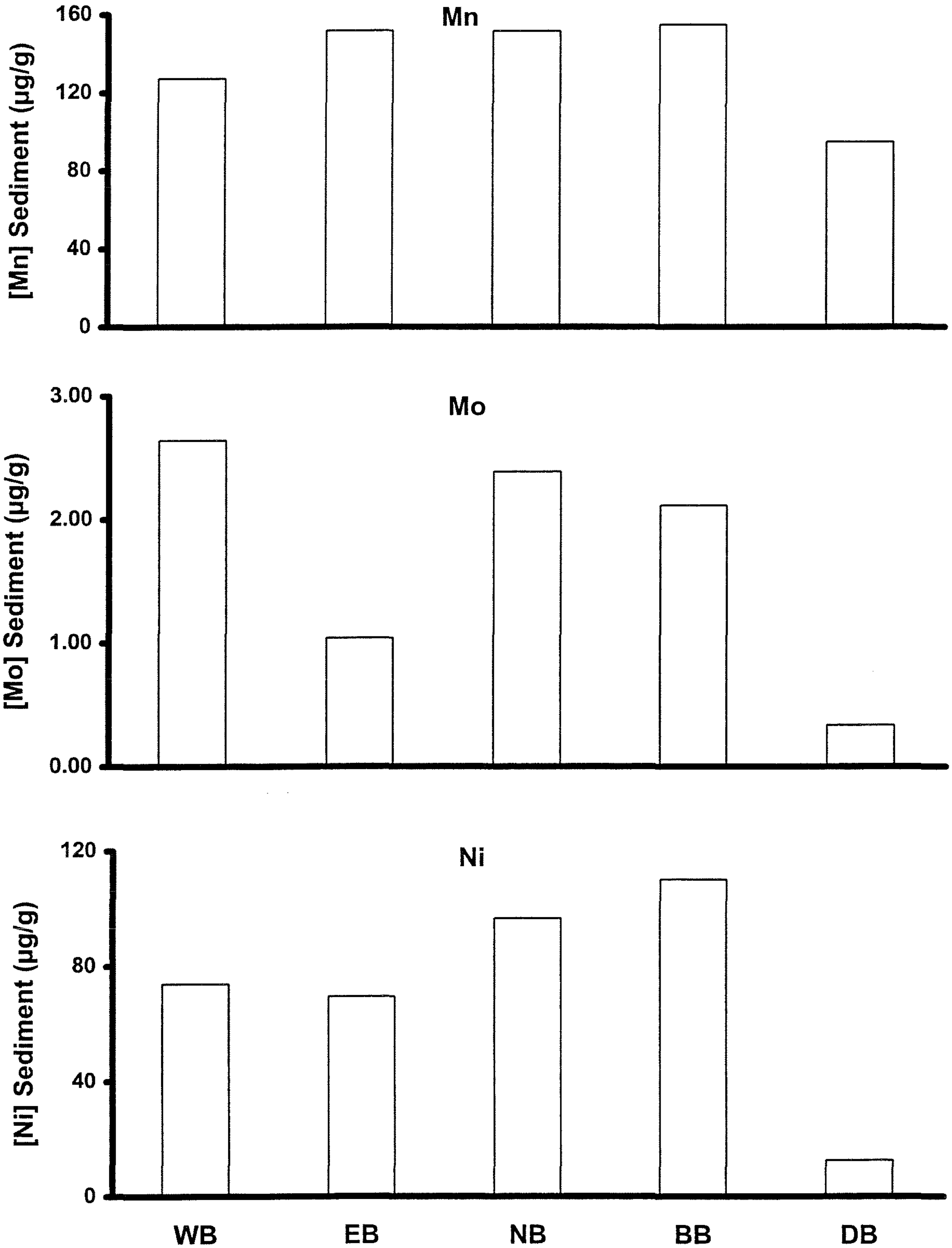

Figure 5d. Mn, Mo, and Ni concentrations (µg/g) in Bras d' Or Lake sediment.

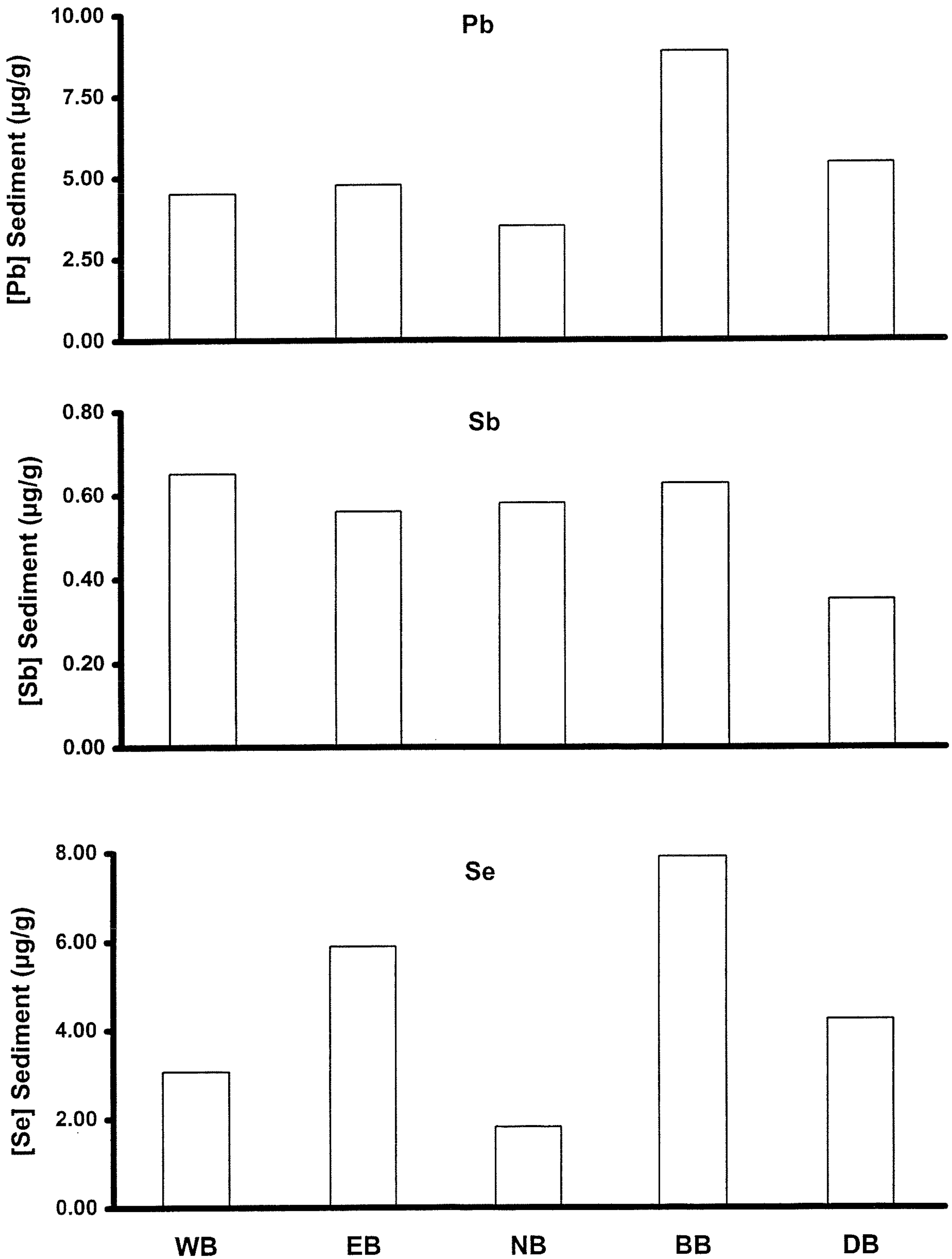

Figure 5e. Pb, Sb, and Se concentrations (µg/g) in Bras d' Or Lake sediment.

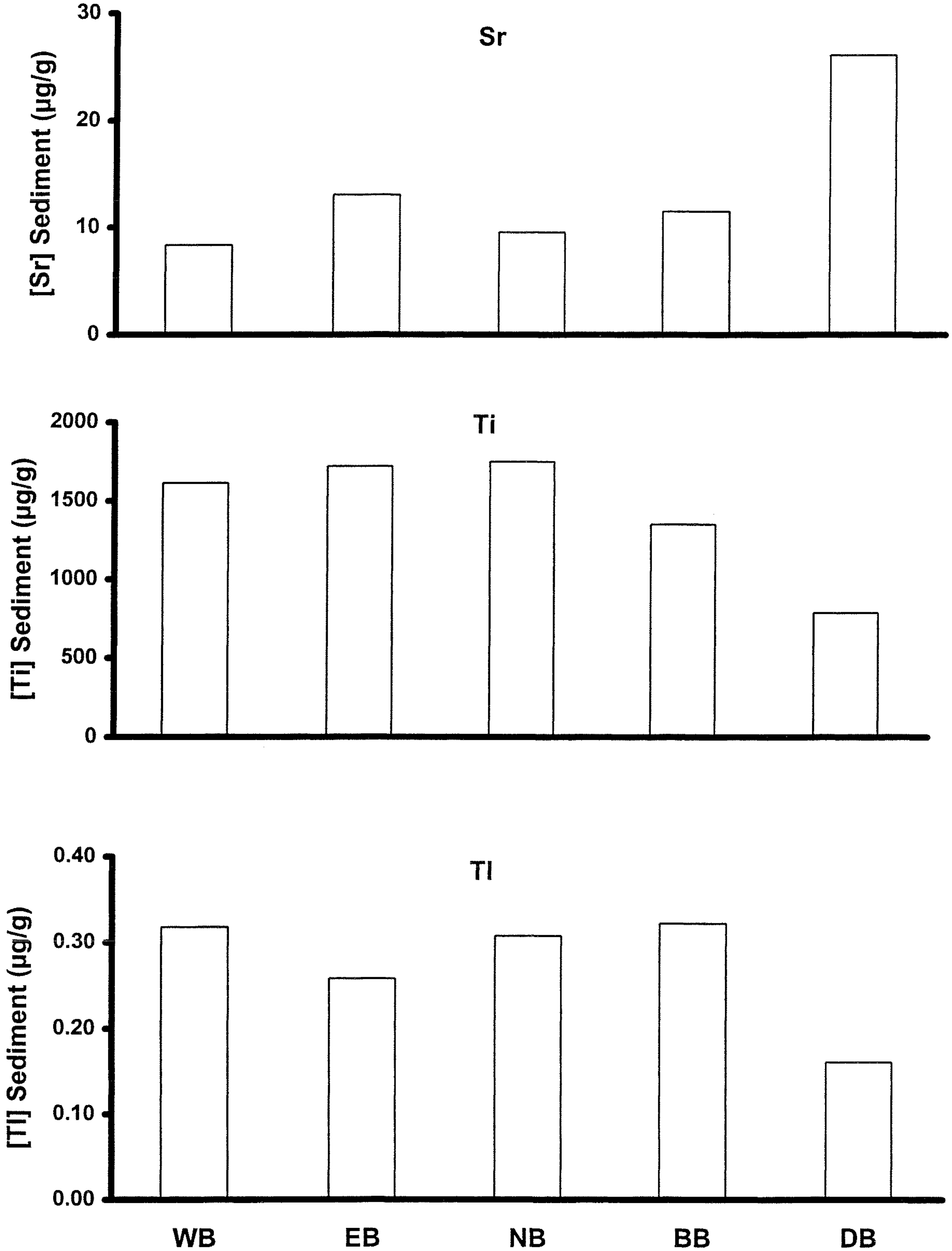

Figure 5f. Sr, Ti, and Tl concentrations (µg/g) in Bras d' Or Lake sediment.

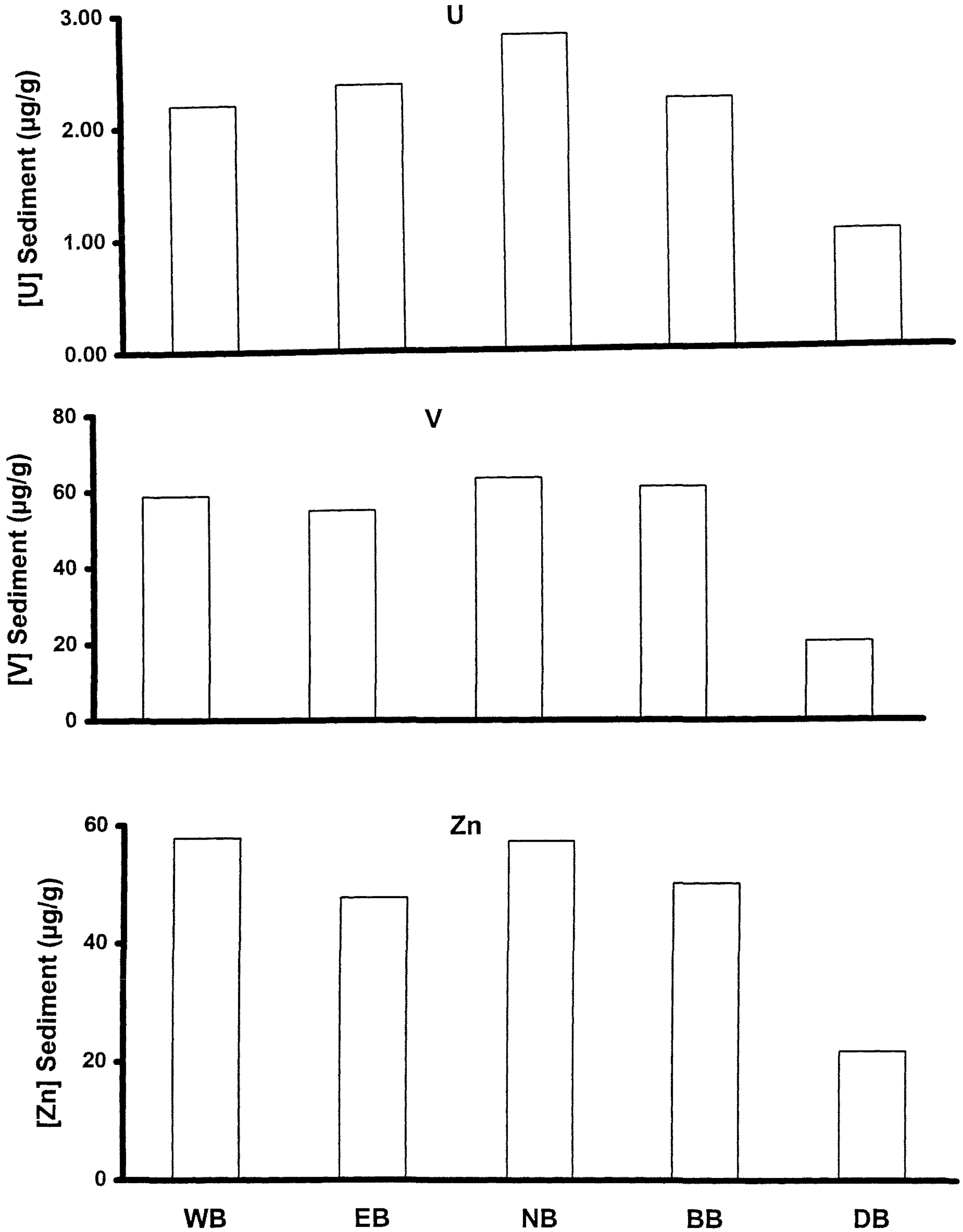

Figure 5g. U, V, and Zn concentrations (µg/g) in Bras d' Or Lake sediment.

3.3. RANKING FOR GEOGRAPHICAL DISTRIBUTION OF METALS

For each sample type, sites were ranked based on the overall metal content. To determine rankings, the highest concentration of a given metal (despite the site) was assigned a value of 1.00. For the same metal, levels at other sites were assigned scores based on their percentage of the highest concentration. Scores for other metals were derived in the same manner. Scores for all metals at a site were then summated, and the generated sums were ranked: highest being 1^{st}, 2^{nd} highest ranked 2, etc.).

3.3.1. LIVER

Final rankings for flounder liver (Table 5):
EB > WB > BB > DB > NB

The following is a score of the geographic site rankings for each metal in liver (Fig. 6):

Baddeck:

Baddeck flounder had the highest scores for Cr, Pb,V and Zn (1.00), and high scores for Ag (0.994), Se (0.764), Be (0.978), Cu (0.965), Mn (0.877) and Li (0.821). Mo (0.606), Ti (0.593), Cd (0.568), As (0.524), Co (0.512), and Sr (0.440) had medium values. Lowest scores were for Ni (0.346), Tl (0.333), U (0.167) and La (0.167). Sb was not detected in liver. Livers in Baddeck flounder had an overall rank of 3.

Denys Basin:

Denys Basin had high scores for Cr and Li (1.00), Ag (0.370), Zn (0.966), Se (0.665), Be (0.783), Cu (0.756), U (0.708), Ti (0.700), Mn (0.677), Sr (0.624), and Mo (0.562). The lowest values were Co (0.443), Cd (0.414), Ni (0.300), As (0.218),V (0.188) and Pb (0.038). La and Sb were not detected. Denys Basin had an overall rank of 4 for liver metal content.

East Bay:

In flounder liver at East Bay, several metals ranked either first or high; Ag, As, Cu, Mn, Sr, Ti, Tl, U (all 1.00), Cr (0.945), Ni (0.927), Cd (0.922), Li (0.910), Zn (0.855), Co (0.802), Pb (0.802), Mo (0.797), and Se (0.751). Be (0.587) and V (0.471) had lower scores. La and Sb were undetected. East Bay flounder ranked 1 for overall liver metals.

Nyanza Bay:

Highest scores for Nyanza Bay flounder liver were: Se (0.69), Ag (0.278), Li (0.985), Zn (0.961), Cr (0.891), Mn (0.711), Mo (0.673), Cd (0.628), Ti (0.578), Cu (0.553), U (0.542), and Tl (0.500). Scores for all other elements were lower: Sr (0.487), Pb(0.169), Co (0.426), V (0.393), Be (0.304), Ni (0.271), and As (0.250). Overall, Nyanza Bay flounder liver, ranked last (5) for relative metal content.

Whycocomagh Bay:

Liver in flounder from Whycocomagh Bay had highest scores for: Be, Cd, Co, Mo, Ni (1.00), Ag (0.704), Zn (0.932), Mn (0.893), Ti (0.881), Cu (0.836), Cr (0.808), U (0.792), Se

(0.668), Li (0.731) and Sr (0.616). The following metals had scores of 5.00 or less: Tl (0.500), V (0.377), As (0.266), and Pb (0.181), and La (0.5) Overall, Whycocomagh Bay ranked 2 for metals in flounder liver.

Table 5. Site ranking by metal concentrations in the livers of Bras d'Or Lake flounder.

	BB	**DB**	**EB**	**NB**	**WB**
Ag	0.944	0.370	1.000	0.278	0.704
As	0.524	0.218	1.000	0.250	0.266
Be	0.978	0.783	0.587	0.304	1.000
Cd	0.568	0.414	0.922	0.628	1.000
Co	0.512	0.443	0.802	0.426	1.000
Cr	1.000	1.000	0.945	0.891	0.808
Cu	0.965	0.756	1.000	0.553	0.836
La	0.167	0.000	1.000	0.000	0.500
Li	0.821	1.000	0.910	0.985	0.731
Mn	0.877	0.677	1.000	0.711	0.893
Mo	0.606	0.562	0.797	0.673	1.000
Ni	0.346	0.300	0.927	0.271	1.000
Pb	1.000	0.038	0.800	0.169	0.181
Sb	0.000	0.000	0.000	0.000	0.000
Se	0.764	0.665	1.000	0.619	0.668
Sr	0.440	0.624	1.000	0.487	0.616
Ti	0.593	0.700	1.000	0.578	0.881
Tl	0.333	0.500	1.000	0.500	0.500
U	0.167	0.708	1.000	0.542	0.792
V	1.000	0.188	0.471	0.393	0.377
Zn	1.000	0.966	0.855	0.961	0.932
TOTAL	13.605	10.912	18.02	10.219	14.685
RANK	3	4	1	5	2
SITE	**BB**	**DB**	**EB**	**NB**	**WB**

Figure 6. Site rankings for metal concentrations (μg/g) in liver.

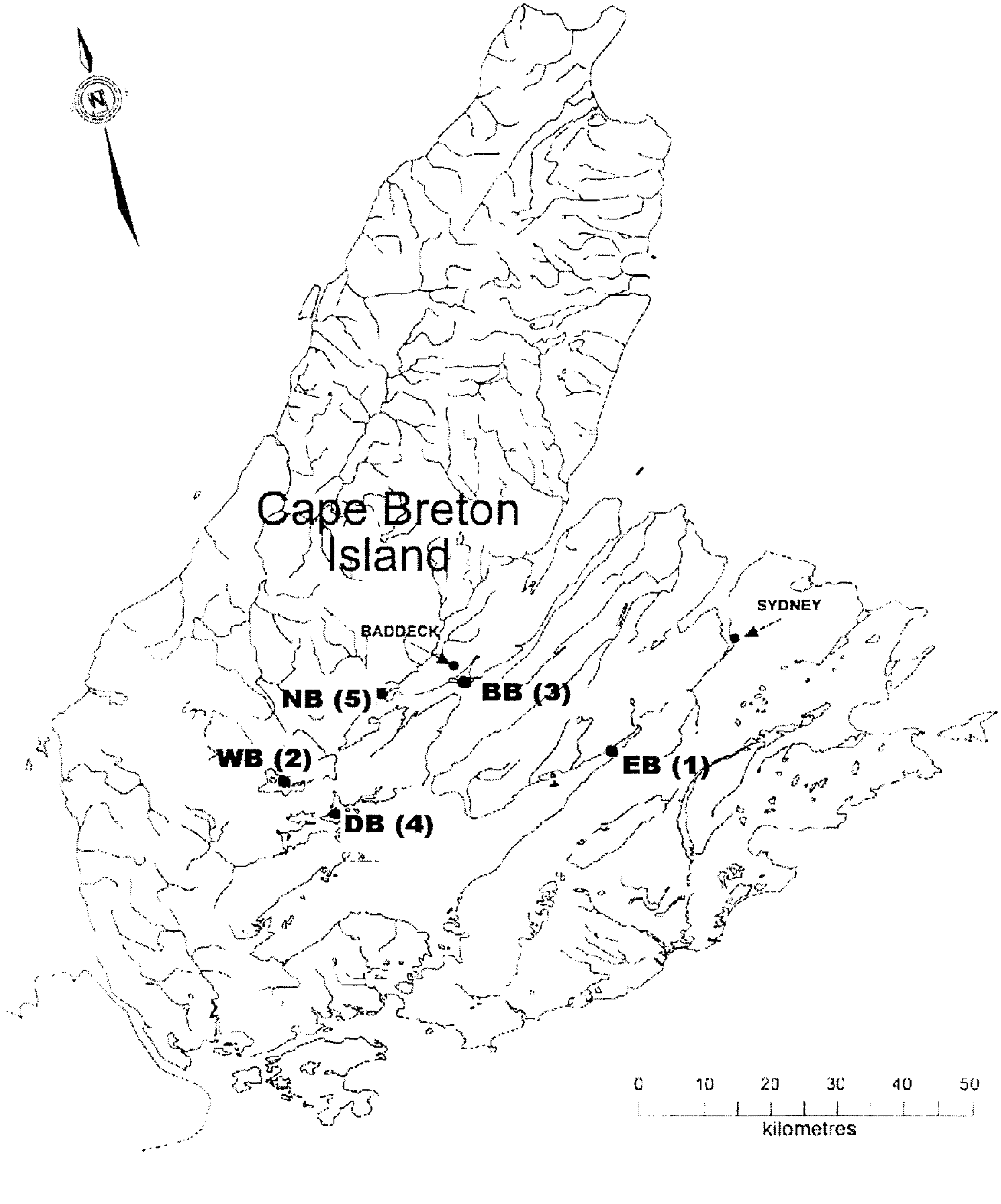

Figure 6. Site rankings for metal concentrations (μg/g) in liver.

3.3.2. KIDNEY

Final rankings for flounder kidney (Table 6):
EB > BB > WB > DB > NB

The following is a summary of the geographic site rankings for each metal in kidney (Fig. 7):

Baddeck:

In Baddeck flounder, highest scores for the kidney were As, Li, Mn, Pb, Ti, and V (1.00). Cu (0.915), Zn (0.891), Sr (0.829) and Cr (0.802), Se (0.661), and Be (0.714) also had high scores. The following metals scored below 0.600: Mo (0.580), Ni (0.559), Cd (0.554),Tl (0.500), Co (0.488),and U (0.371). La and Sb were not detected. Kidney in Baddeck flounder had an overall rank of 2.

Denys Basin:

At Denys Basin, Be, Cr, Zn (1.00), and Li (0.980), Cu (0.908), and Ti (0.886) all had high scores. Mo (0.796), Tl (0.750), and Sr (0.746) scores were similar. Lower scores occurred for Mn (0.671), Ni (0.666), U (0.657), As (0.563), Co (0.516), Cd (0.500), V (0.382), Se (0.656) and Pb (0.090). Denys Basin had an overall rank of 4.

East Bay:

Kidneys from East Bay flounder had high scores for Cd, Co, Cu, Ni, Se, Sr, Tl, U, (all 1.00) and Ti (0.989), Zn (0.981), Pb (0.929), Mo (0.921), Li (0.920), Mn (0.897), As (0.830), Cr (0.824), and Be (0.794). The lowest score at this site was for V (0.548). East Bay flounder ranked 1 for overall kidney metal content.

Nyanza Bay:

In the kidney of flounder collected at Nyanza Bay, none of the metals had highest ranking. High values were found for: Be (0.968), Li (0.940), Cr(0.842), Co (0.823), Se (0.619), Zn (0.794), Cu (0.784),Ti (0.747), Ni (0.681), Mo (0.670), and Mn (0.612). Lower values were derived for Sr (0.579), Cd (0.548), U (0.514), Tl (0.500), Pb (0.494), As (0.489), and V (0.446). Overall, Nyanza Bay flounder kidney ranked last for metal content.

Whycocomagh Bay:

Whycocomagh Bay flounder had the highest score for Mo (1.00), Zn (0.997), Ti (0.986), Cu (0.901), Cd (0.898), Sr (0.844), Li (0.820), Mn (0.819), Co (0.814), V (0.812), Be (0.810), Cr (0.801), Se (0.627), As (0.686) and U(0.629). The following metals had the lowest scores: Ni (0.598), Tl (0.500), and Pb

(0.080). La and Sb were not detected. Overall, kidney in Whycocomagh Bay flounder ranked 3 for metal content.

Table 6. Site ranking by metal concentrations in the kidneys of Bras d'Or Lake flounder.

Metal	**BB**	**DB**	**EB**	**NB**	**WB**
Ag	0.000	0.000	0.000	0.000	0.000
As	1.000	0.563	0.830	0.489	0.686
Be	0.714	1.000	0.794	0.968	0.810
Cd	0.554	0.500	1.000	0.548	0.898
Co	0.488	0.516	1.000	0.823	0.814
Cr	0.802	1.000	0.824	0.842	0.801
Cu	0.915	0.908	1.000	0.784	0.901
La	0.000	0.000	0.000	0.000	0.000
Li	1.000	0.980	0.920	0.940	0.820
Mn	1.000	0.671	0.897	0.612	0.819
Mo	0.580	0.796	0.921	0.670	1.000
Ni	0.559	0.666	1.000	0.681	0.598
Pb	1.000	0.090	0.929	0.494	0.080
Sb	0.000	0.000	0.000	0.000	0.000
Se	0.661	0.656	1.000	0.619	0.627
Sr	0.829	0.746	1.000	0.579	0.844
Ti	1.000	0.886	0.989	0.747	0.986
Tl	0.500	0.750	1.000	0.500	0.500
U	0.371	0.657	1.000	0.514	0.629
V	1.000	0.382	0.548	0.446	0.812
Zn	0.891	1.000	0.981	0.794	0.997
TOTAL	13.864	12.767	16.633	12.050	13.622
RANK	2	4	1	5	3
SITE	**BB**	**DB**	**EB**	**NB**	**WB**

Figure 7. Site rankings for metal concentrations (μg/g) in kidney.

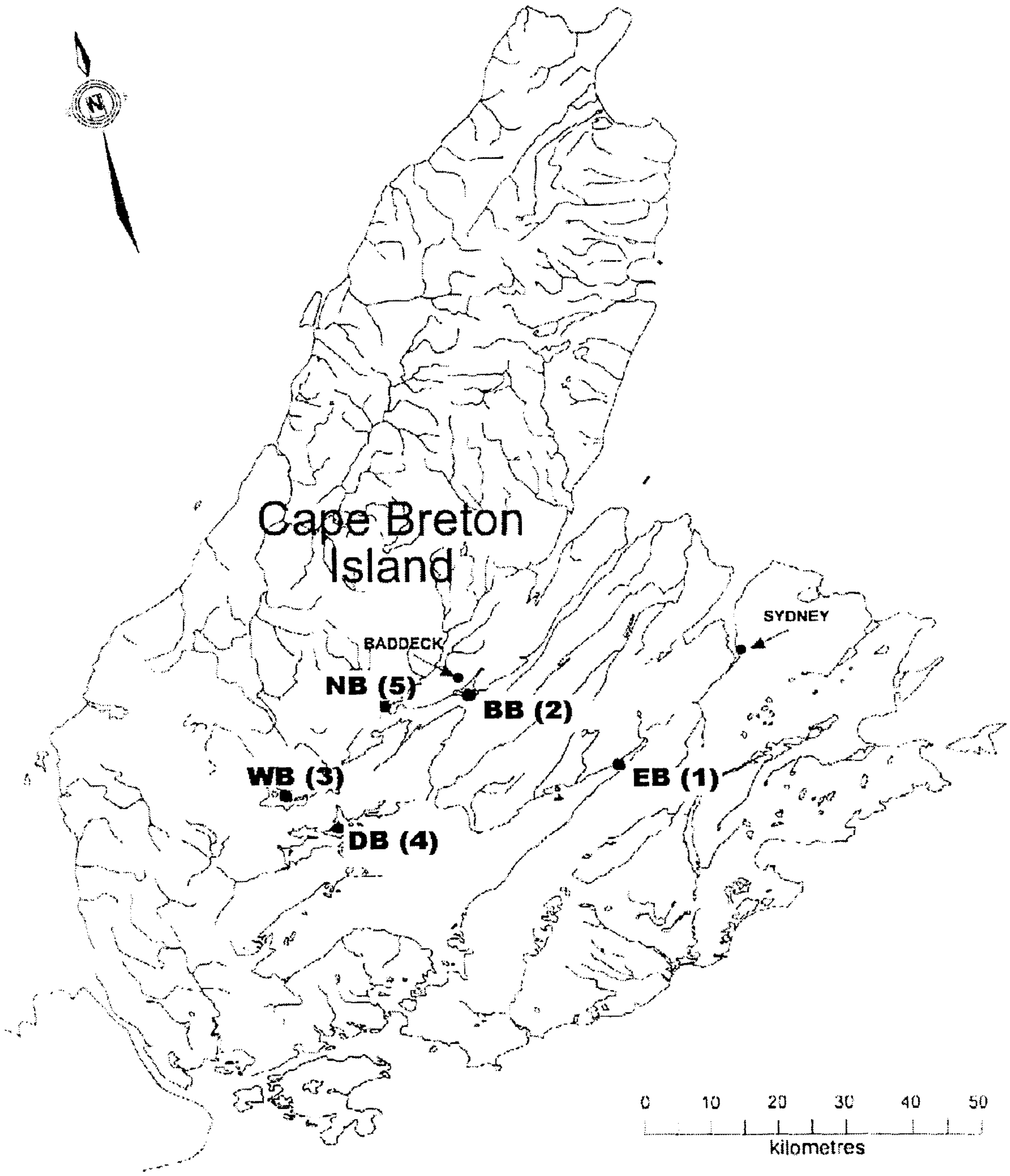

Figure 7. Site rankings for metal concentrations (μg/g) in kidney.

3.3.3. SEDIMENTS

Final rankings for Bras d'Or Lake sediments (Table 7):
Sediments: BB > NB > WB > EB > DB

The following is a summary of the geographic site rankings for metals in sediments (Fig. 8):

Baddeck:

Baddeck sediments had high scores for Mn (1.00), Ni (1.00), Pb (1.00), Se (1.00), Tl (1.00), La (0.967), Sb (0.964), V (0.959), As (0.954), Ag (0.862), Co, (0.907), Zn (0.868), Cr and Cu (0.847), and Mo (0.801). Medium values were found for U (0.792), Ti (0.772), Cd (0.731), Be (0.680), and Li (0.595). The lowest score was for Sr (0.441). Baddeck sediments had an overall rank of 1.

Denys Basin:

Denys Basin sediments had the highest score for only one element: Sr (1.00). Other than Ag (0.00), La (0.666), Mn and Pb (0.612), Sb (0.539), Se (0.539), and Tl (0.500), scores were generally low. Lowest scores were: Cd (0.478), Ti (0.451), Be (0.397), Zn (0.377), U(0.369), Co (0.363), V (0.324), Cu (0.290), Cr (0.269), Li (0.243), As (0.242), Mo (0.128) and Ni (0.115). Denys Basin sediments ranked last (5), that is, it had the lowest overall metal content.

East Bay:

East Bay sediments had highest scores for only 2 elements: Cu and La (1.00). Ti (0.984), Mn (0.980), Ag (0.667), Cd (0.924), V (0.869), Sb (0.861), U (0.846), Zn (0.825), Tl (0.801), Co (0.789), Se (0.744), Cr (0.706), also had high scores. Li (0.655), Be (0.648), Ni (0.632), Pb (0.539), Sr (0.502) and As (0.433) had the lowest scores. East Bay sediments ranked 4 overall for metal content.

Nyanza Bay:

At Nyanza Bay, sediments ranked highest for Ag, Co, Ti, U, V (1.00), and Zn (0.991), Mn (0.979), Cr and Li (0.958), Tl (0.955), Cd (0.918), Mo (0.904), La and Sb (0.892), Be (0.883), Ni (0.878), As (0.874), and Cu (0.794). Lowest values occurred for Pb (0.396), Sr (0.366), and Se (0.230). Nyanza Bay sediments ranked 2 overall.

Whycocomagh Bay:

Highest scores in sediments from Whycocomagh Bay were for the following metals: As, Be, Cd, Cr, Li, Mo, Sb, Zn (1.00), Tl (0.987), V (0.933), Ag (0.885), Ti (0.923), Co (0.919), Mn (0.822), U (0.785), Cu (0.767), La (0.725) and Ni (0.672). Pb (0.510), Se (0.396) and Sr (0.321), had the lowest scores. Whycocomagh Bay sediments ranked 3 overall, for metal content.

Table 7. Site ranking by metal concentrations in sediments in the Bras d'Or Lake.

	BB	DB	EB	NB	WB
Ag	0.862	0.000	0.667	1.000	0.885
As	0.954	0.242	0.433	0.874	1.000
Be	0.680	0.397	0.648	0.883	1.000
Cd	0.731	0.478	0.924	0.918	1.000
Co	0.907	0.363	0.789	1.000	0.919
Cr	0.847	0.269	0.706	0.958	1.000
Cu	0.847	0.290	1.000	0.794	0.767
La	0.967	0.666	1.000	0.892	0.725
Li	0.595	0.243	0.655	0.958	1.000
Mn	1.000	0.612	0.980	0.979	0.822
Mo	0.801	0.128	0.394	0.904	1.000
Ni	1.000	0.115	0.632	0.878	0.672
Pb	1.000	0.612	0.539	0.396	0.510
Sb	0.964	0.539	0.861	0.892	1.000
Se	1.000	0.539	0.744	0.230	0.396
Sr	0.441	1.000	0.502	0.366	0.321
Ti	0.772	0.451	0.984	1.000	0.923
Tl	1.000	0.500	0.801	0.955	0.987
U	0.792	0.369	0.846	1.000	0.785
V	0.959	0.324	0.869	1.000	0.933
Zn	0.868	0.377	0.825	0.991	1.000
TOTAL	17.987	8.514	15.799	17.868	17.645
RANK	1	5	4	2	3
SITE	**BB**	**DB**	**EB**	**NB**	**WB**

Figure 8. Site rankings for metal concentrations (μg/g) in sediments.

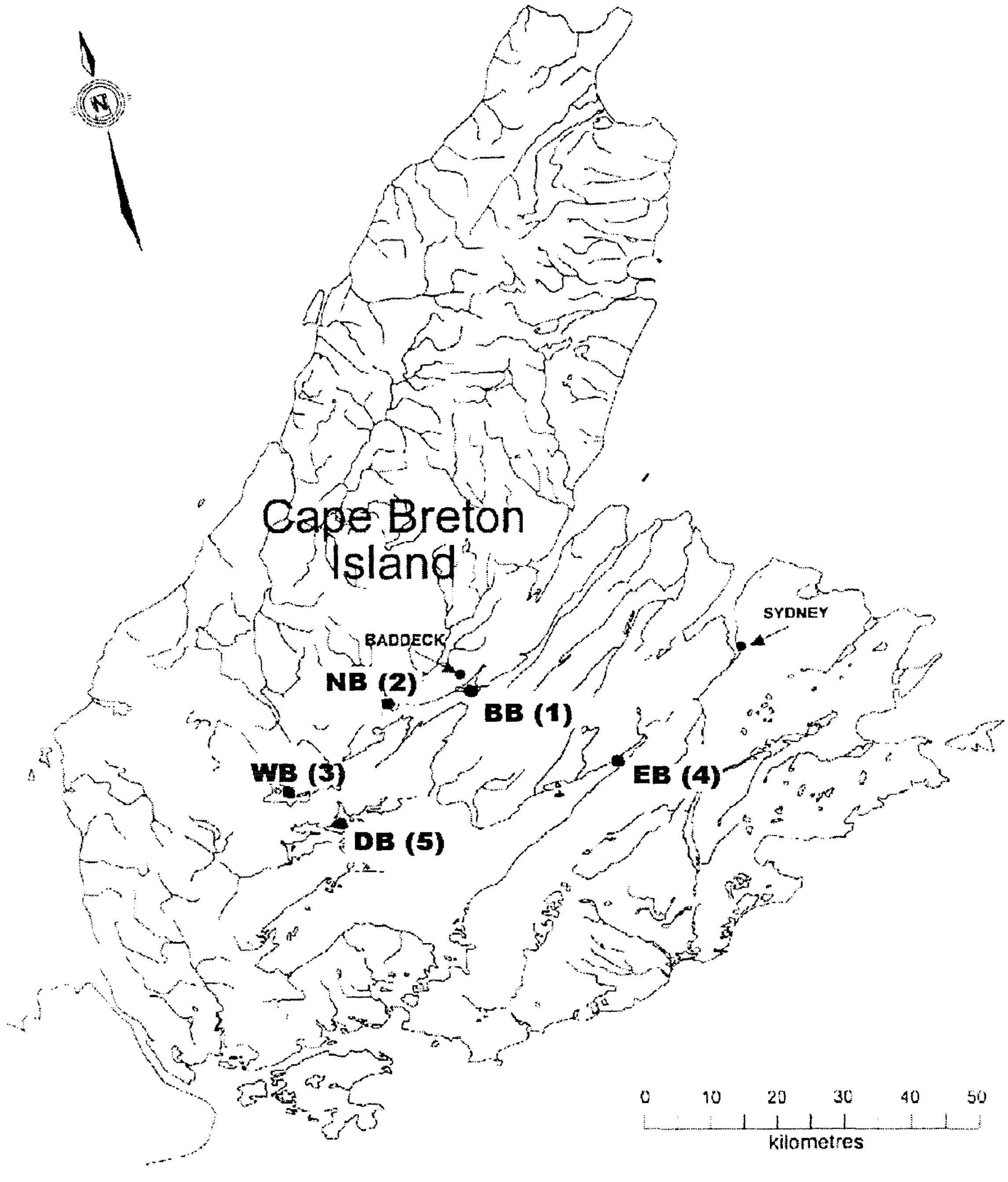

Figure 8. Site rankings for metal concentrations (µg/g) in sediments.

3.4. METAL CONCENTRATION TRENDS

3.4.1. WITH BIOLOGICAL PARAMETERS

3.4.1.1. LIVER

Reverse trends appear between cadmium (weak trend) (Fig. 9a), cobalt (Fig. 9b), molybdenum (Fig. 9c), and nickel (Fig. 9d) concentrations in the liver and liver weight. That is, as liver weight increases, concentrations of these metals decrease.

Figure 9: Trends between metal concentration (μg/g) and liver weight: a) Cd, b) Co, c) Mo, d) Ni.

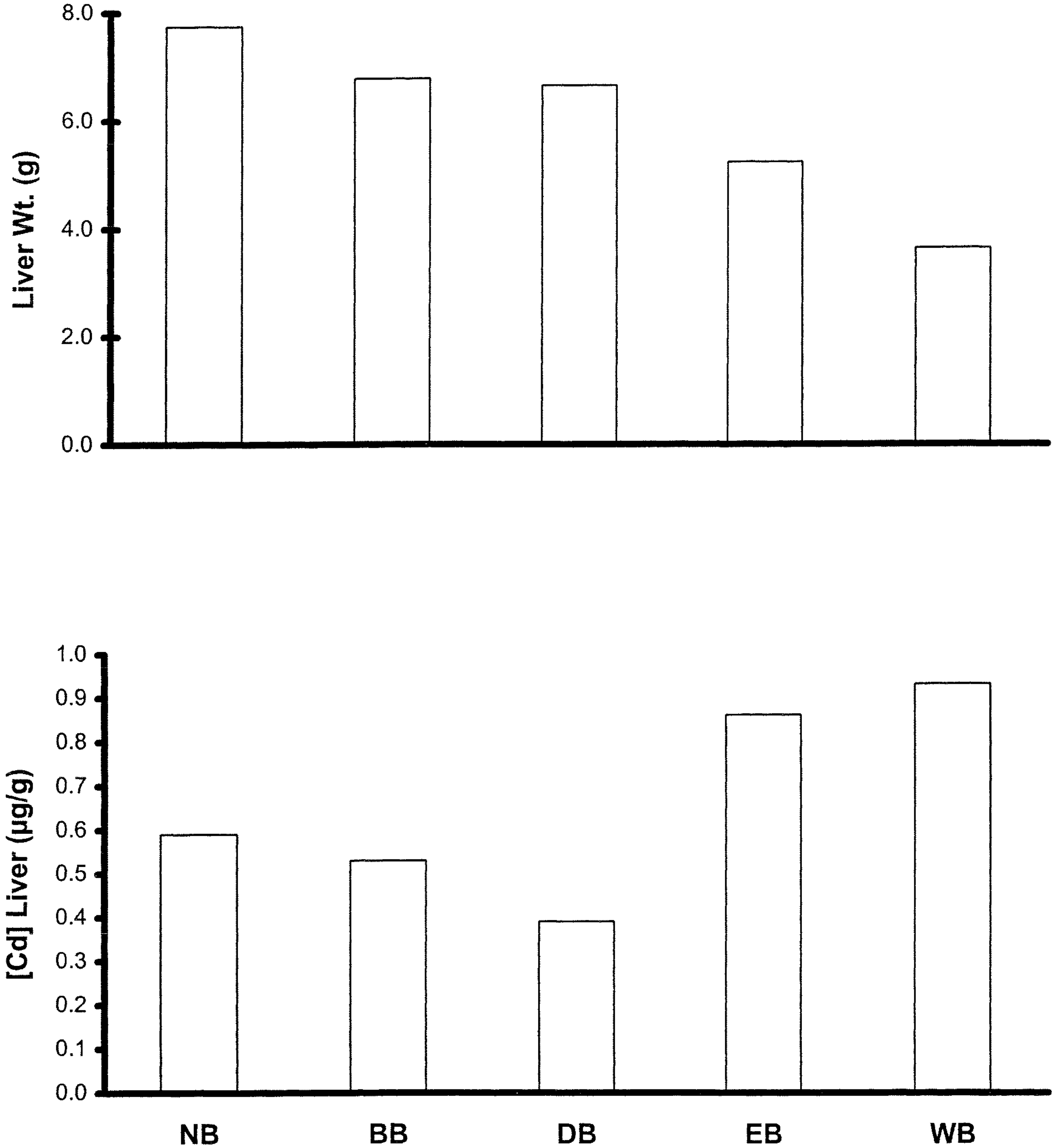

Figure 9a. Reverse trend between Cd concentration (µg/g) in liver and liver weight (g).

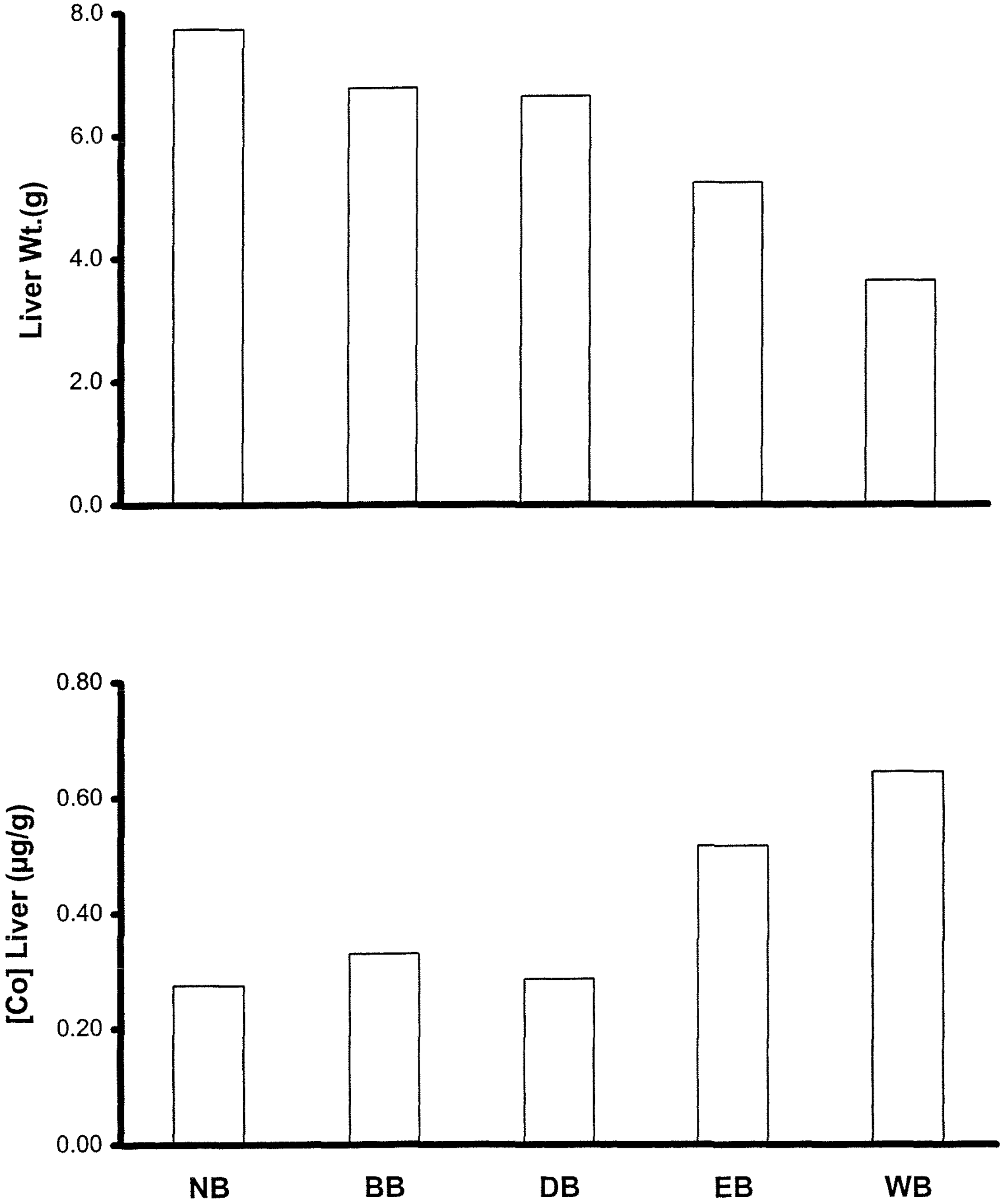

Figure 9b. Reverse trend between Co concentration (µg/g) in liver and liver weight (g).

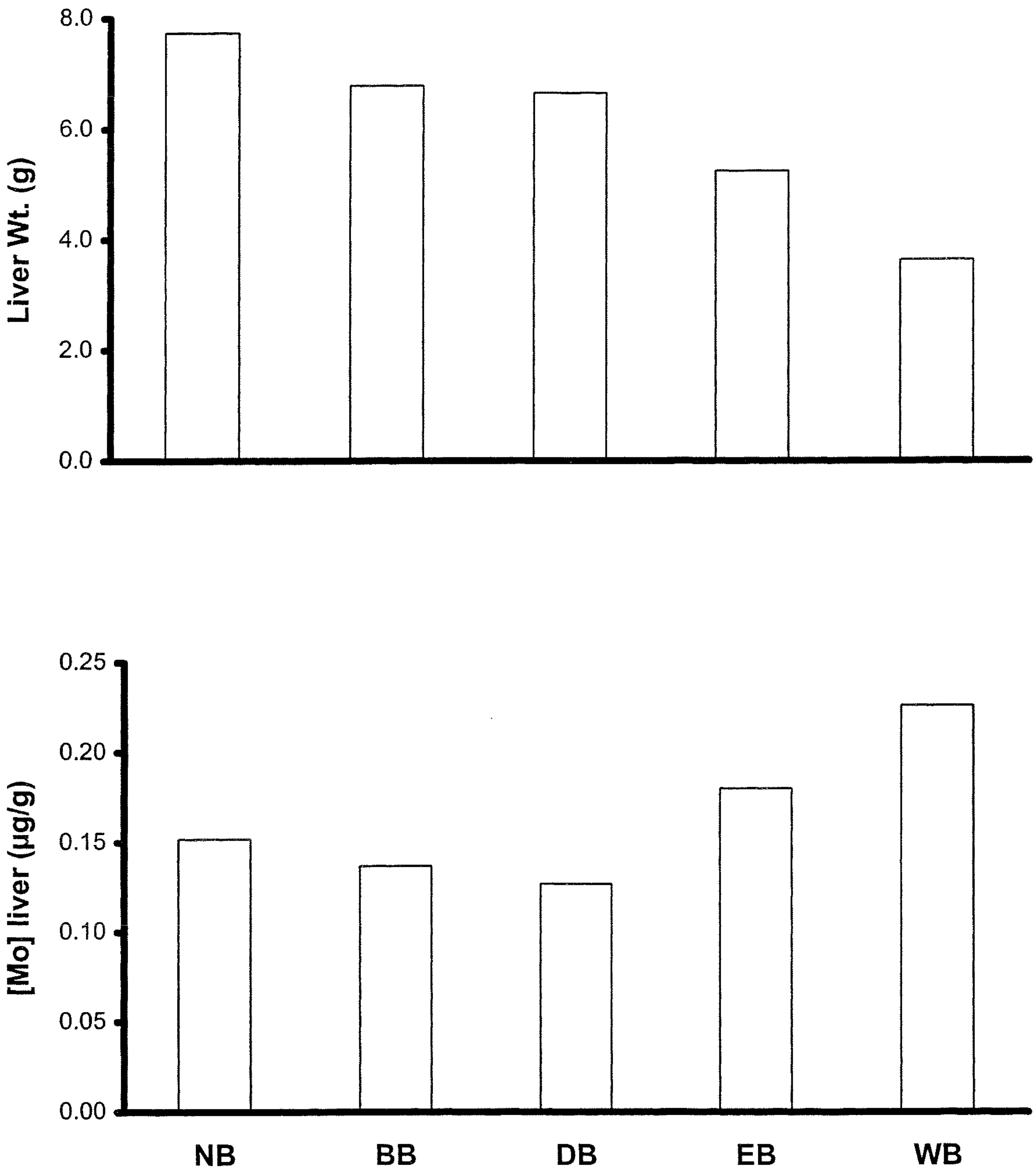

Figure 9c. Reverse trend between Mo concentration (µg/g) in liver and liver weight (g).

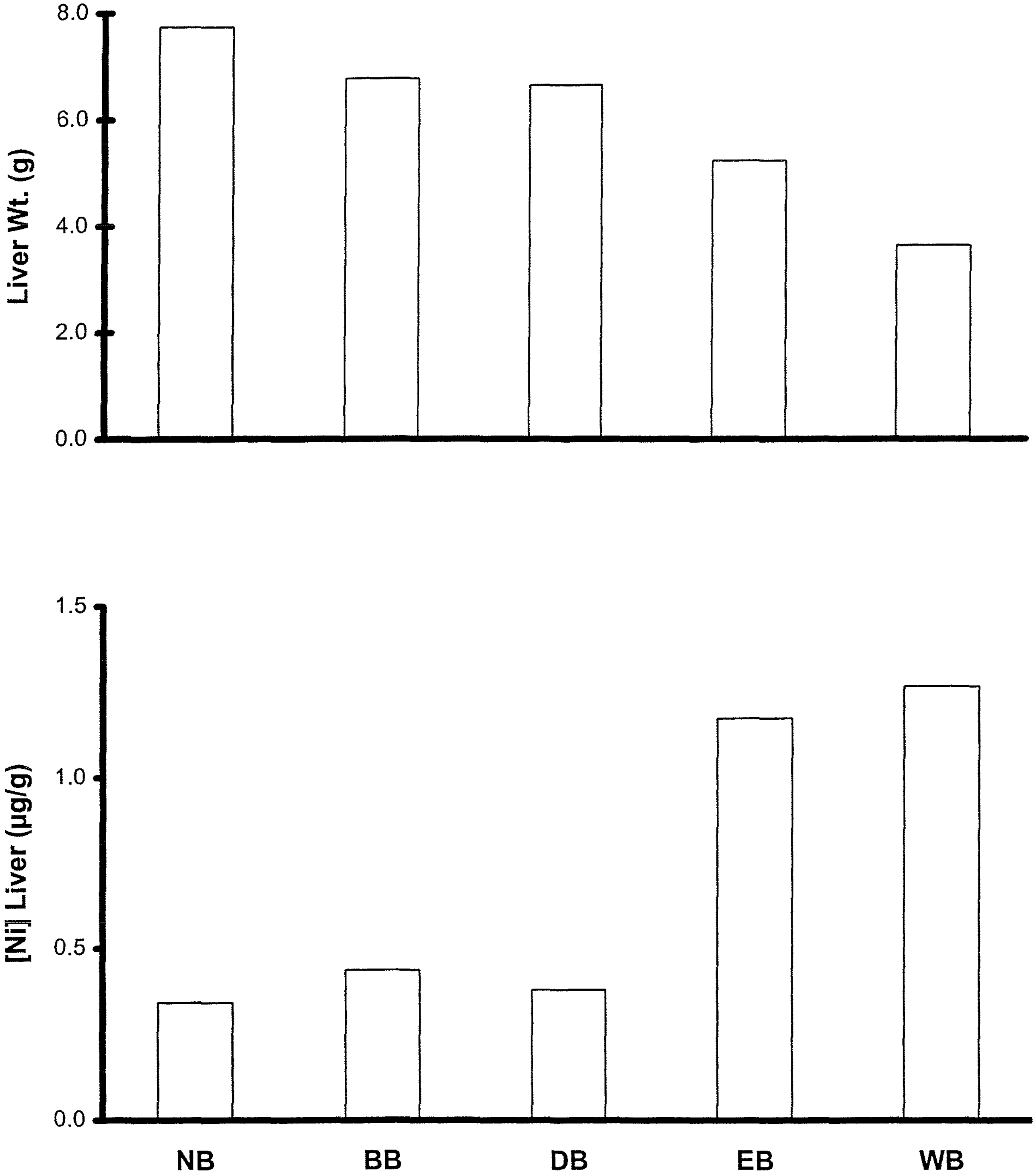

Figure 9d. Reverse trend between Ni concentration (µg/g) in liver and liver weight (g).

3.4.1.2. KIDNEY

Figures 10 (a-c) indicate the concentrations of some metals: copper, molybdenum and titanium, vary in a reverse manner with kidney weight.

Figure 10. Trends between metal concentration (μg/g) and kidney weight (g): a) copper, b) molybdenum, and c) titanium.

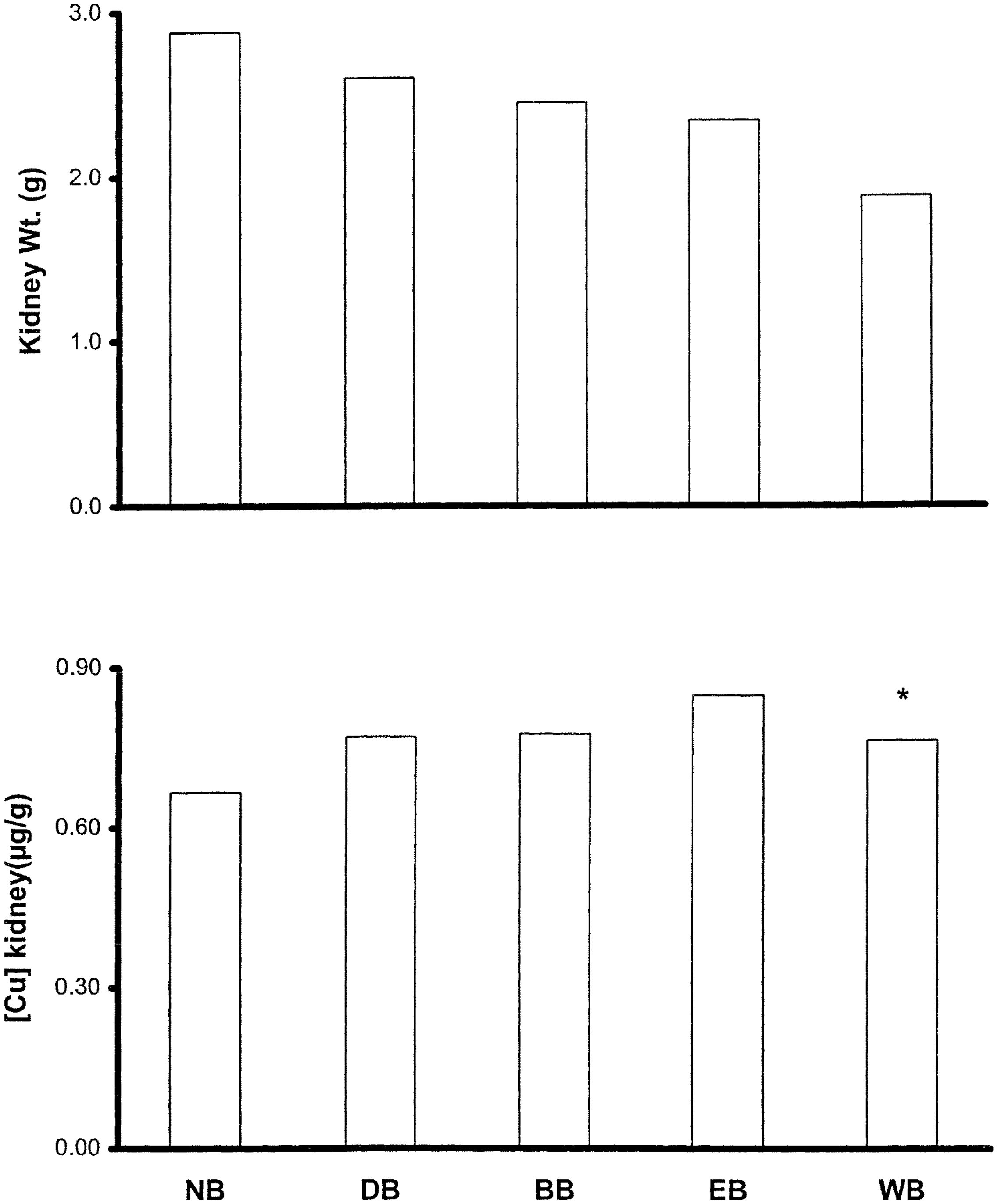

Figure 10a. Reverse trend between Cu concentration (µg/g) in kidney and kidney weight (g).

* Exception

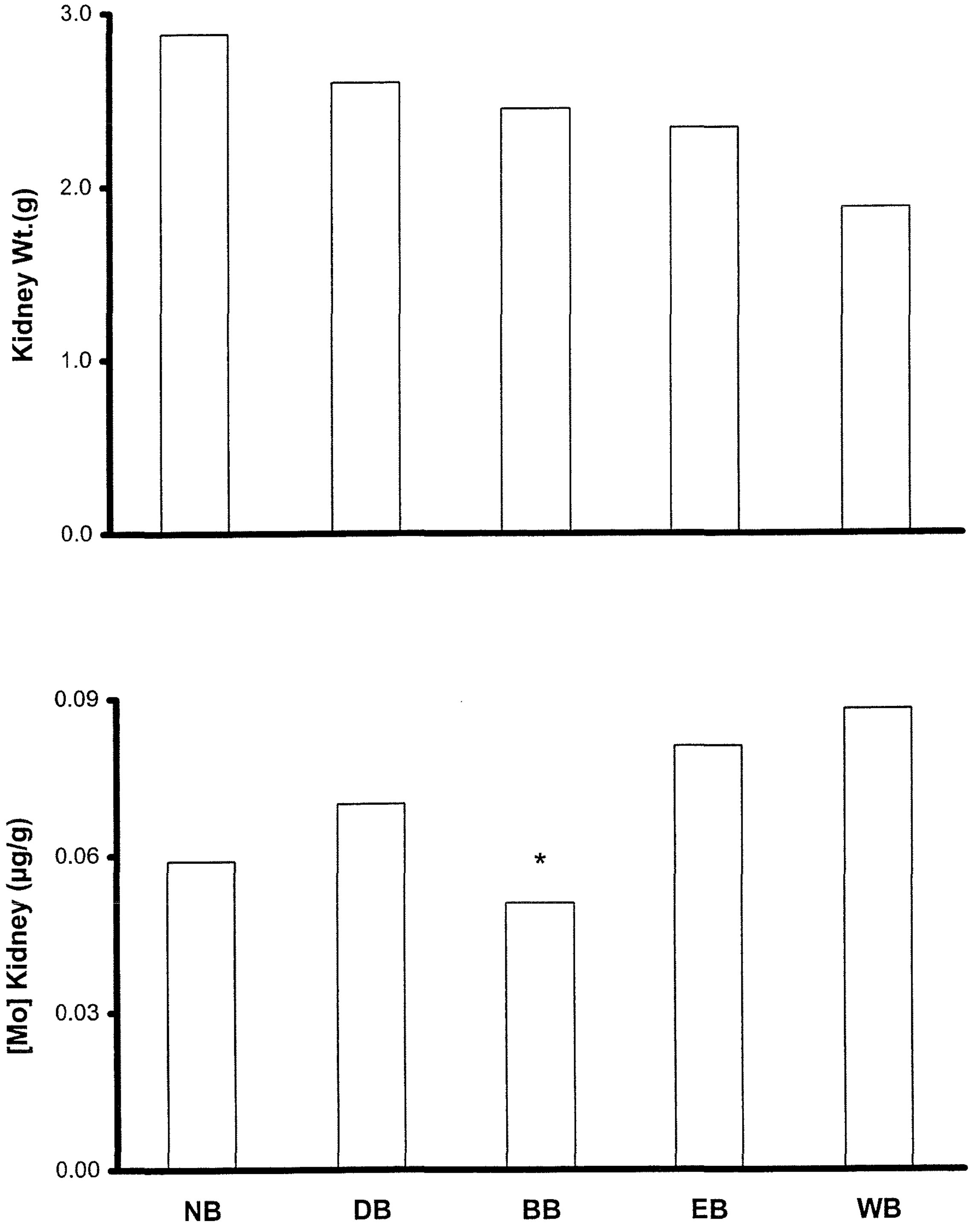

Figure 10b. Reverse trend between Mo concentration (µg/g) in kidney and kidney weight (g).

* Exception

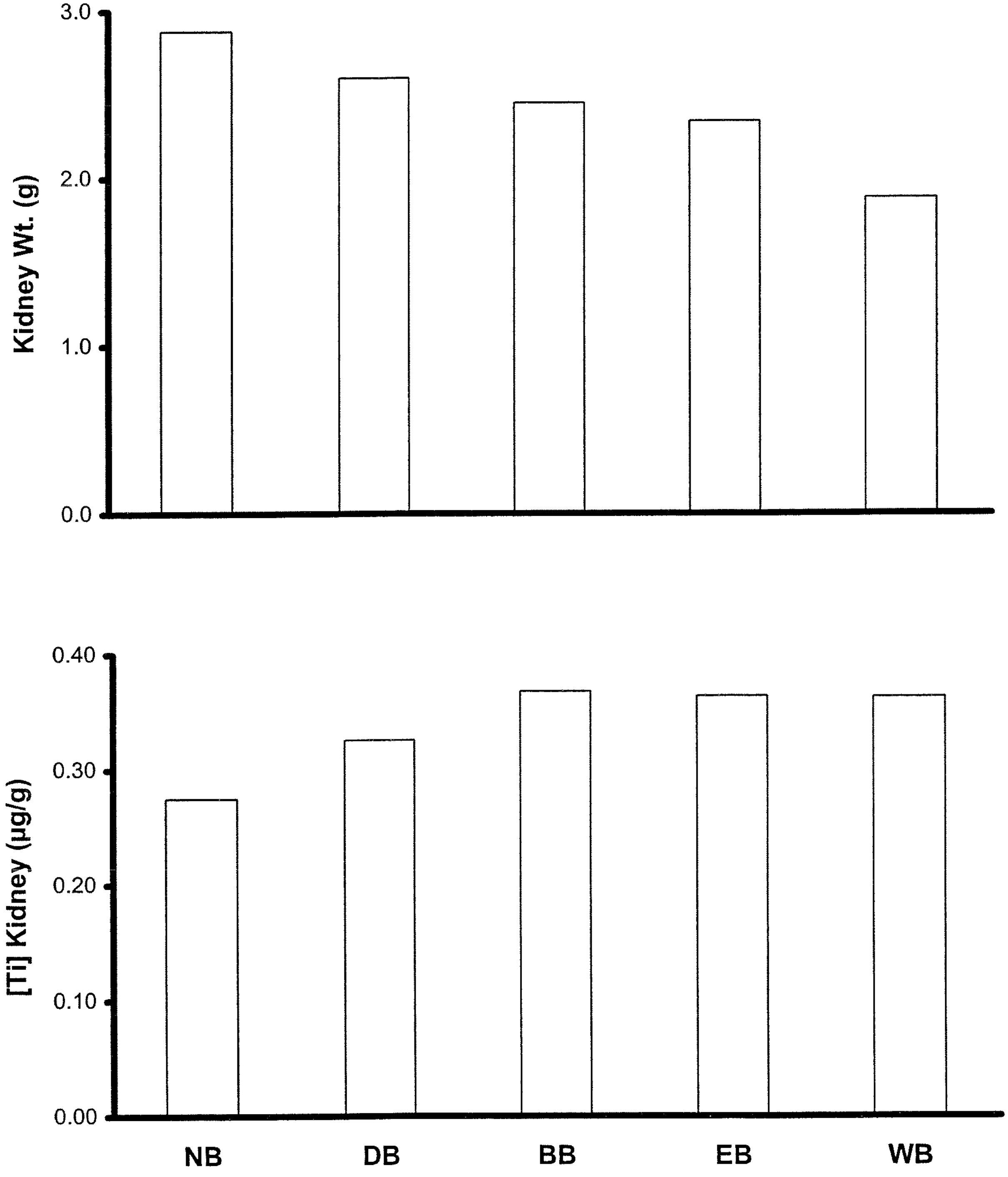

Figure 10c. Reverse trend between Ti concentration (µg/g) in kidney and kidney weight (g).

3.4.2. BETWEEN TISSUES

Elemental levels in flounder liver and kidney appear to be positively related for several elements: cadmium (Fig. 11a.), copper (Fig. 11b.), molybdenum (Fig. 11c.), lead (Fig. 11d.), selenium (Fig. 11e), strontium (Fig. 11f.), thallium (Fig. 11g.), uranium (Fig. 11h.), and vanadium (Fig. 11i.).

Figure 11. Trends between liver and kidney metal concentrations (μg/g): a) Cd, b) Cu, c) Mo, d) Pb, e) Se, f) Sr, g) Tl, h) U, and i) V.

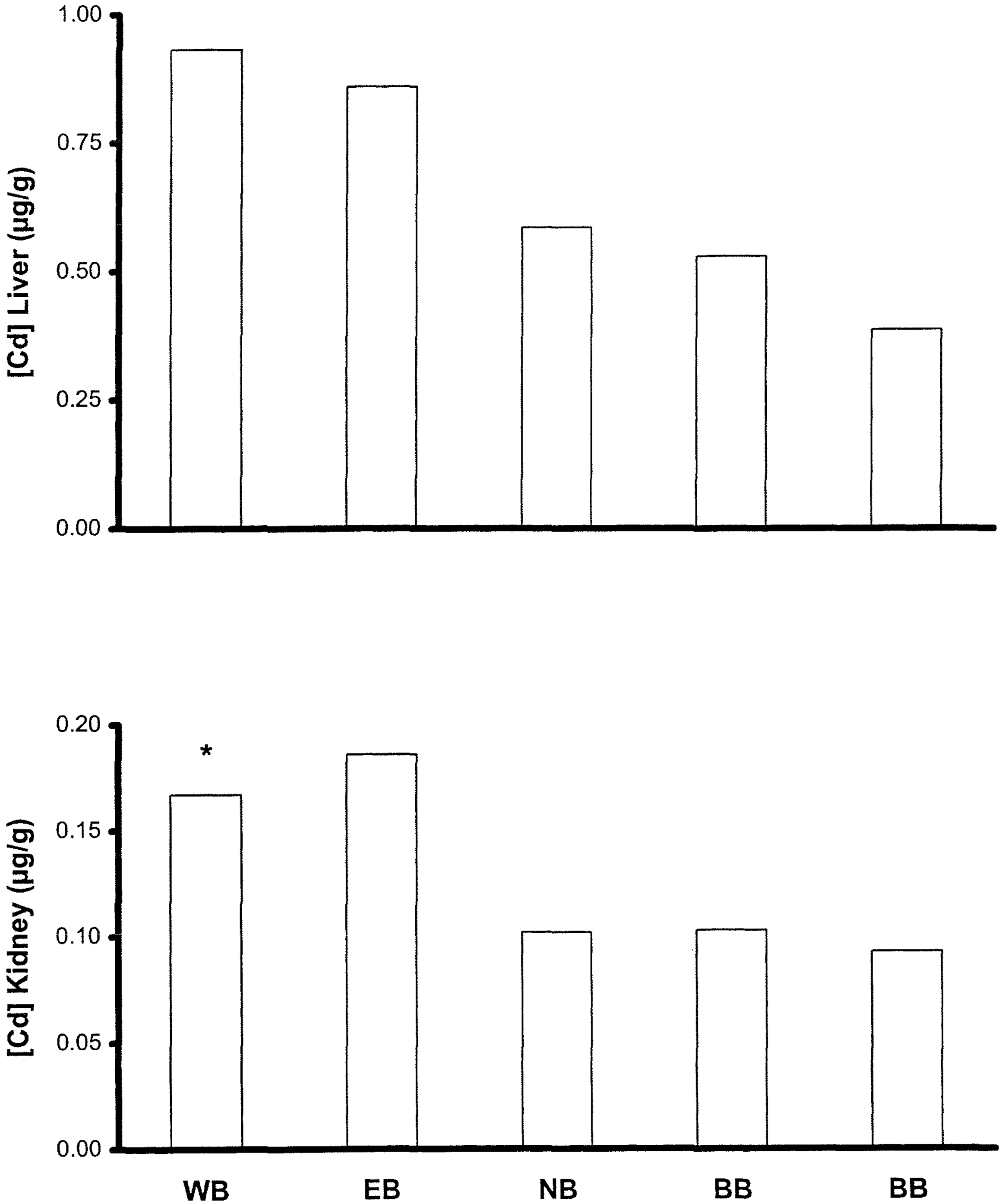

Figure 11a. Trend between Cd concentration (µg/g) in liver and kidney .

* Exception

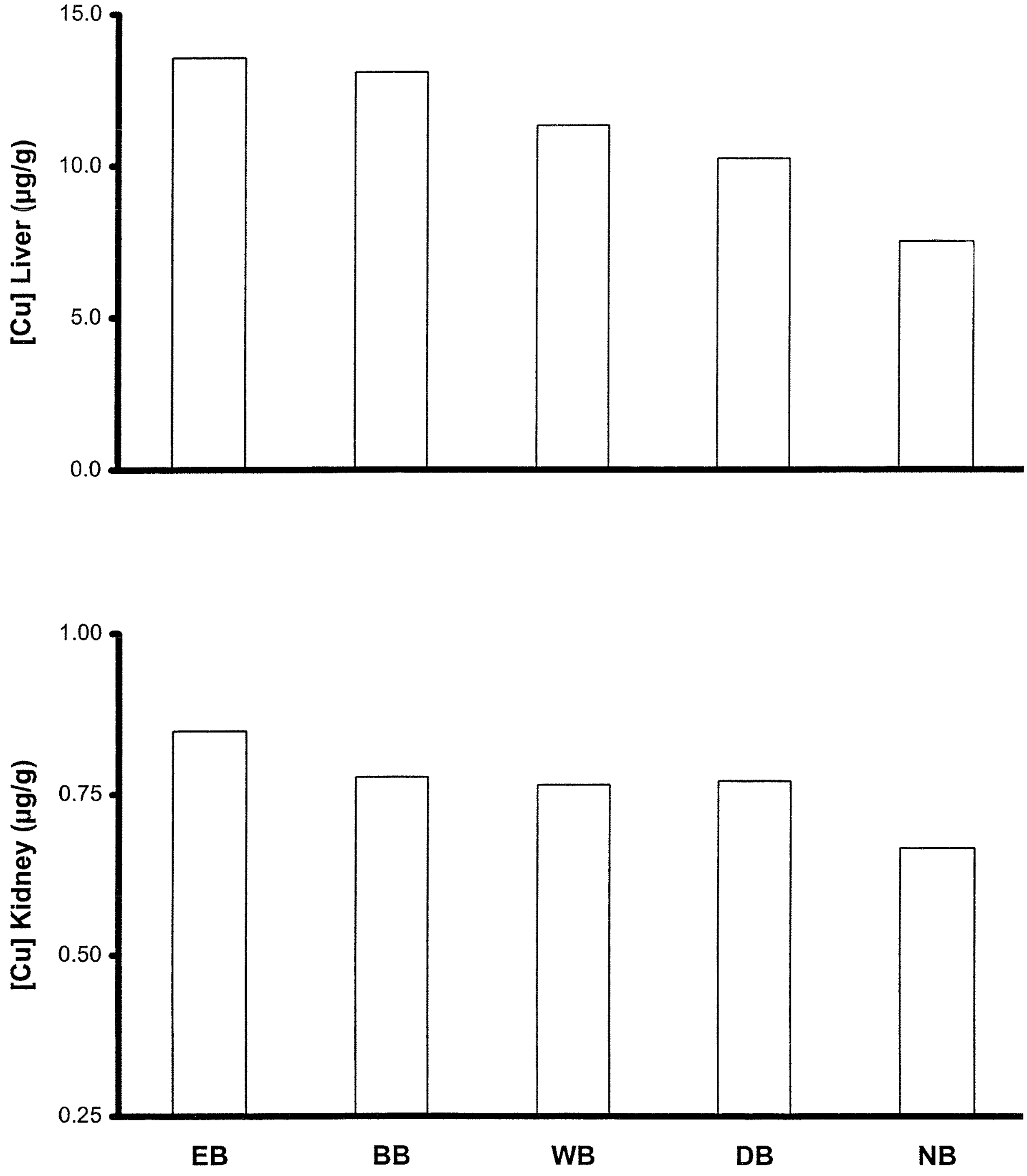

Figure 11b. Trend between Cu concentration (µg/g) in liver and kidney .

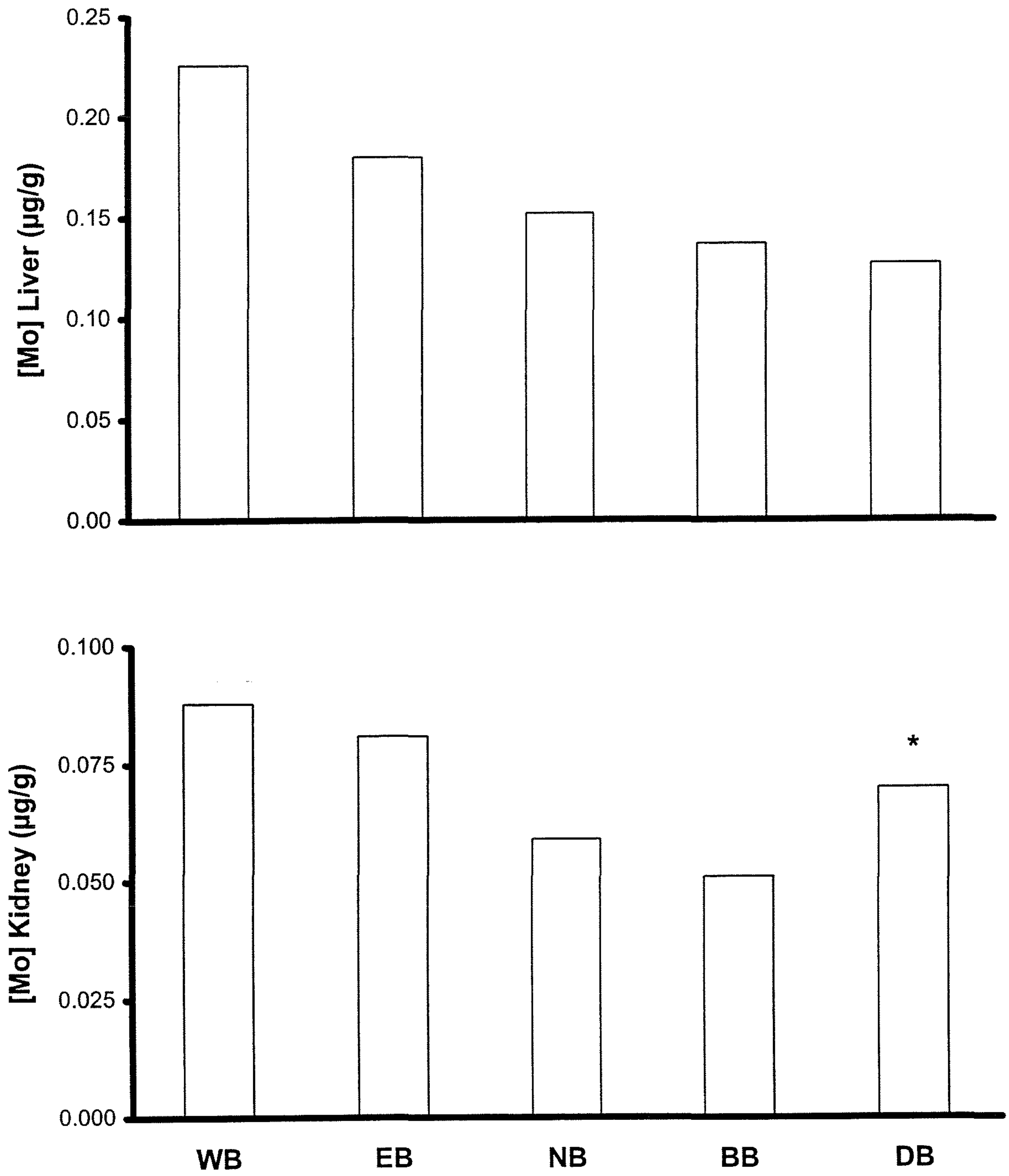

Figure 11c. Trend between Mo concentration (µg/g) in liver and kidney .

* Exception

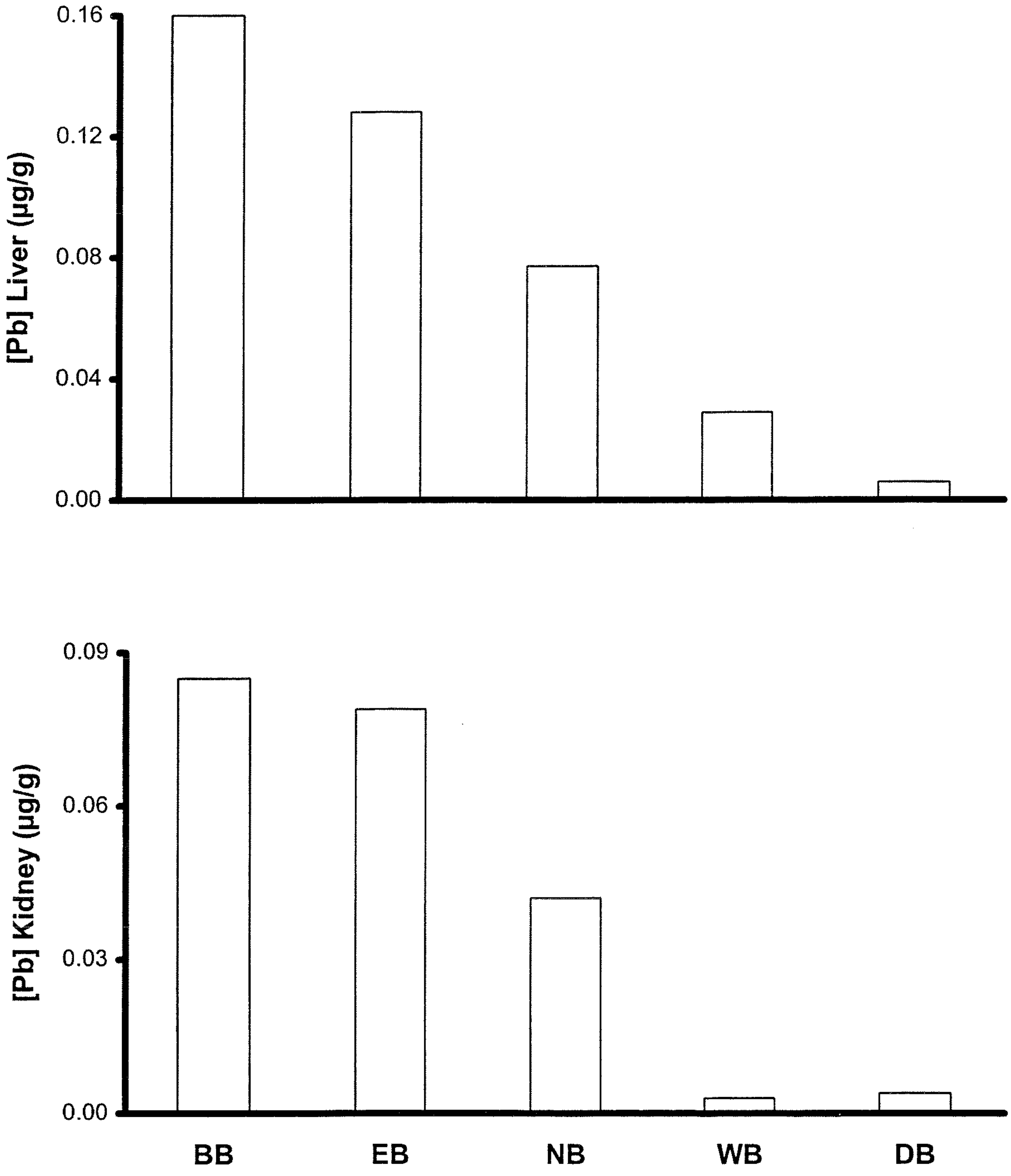

Figure 11d. Trend between Pb concentration (µg/g) in liver and kidney .

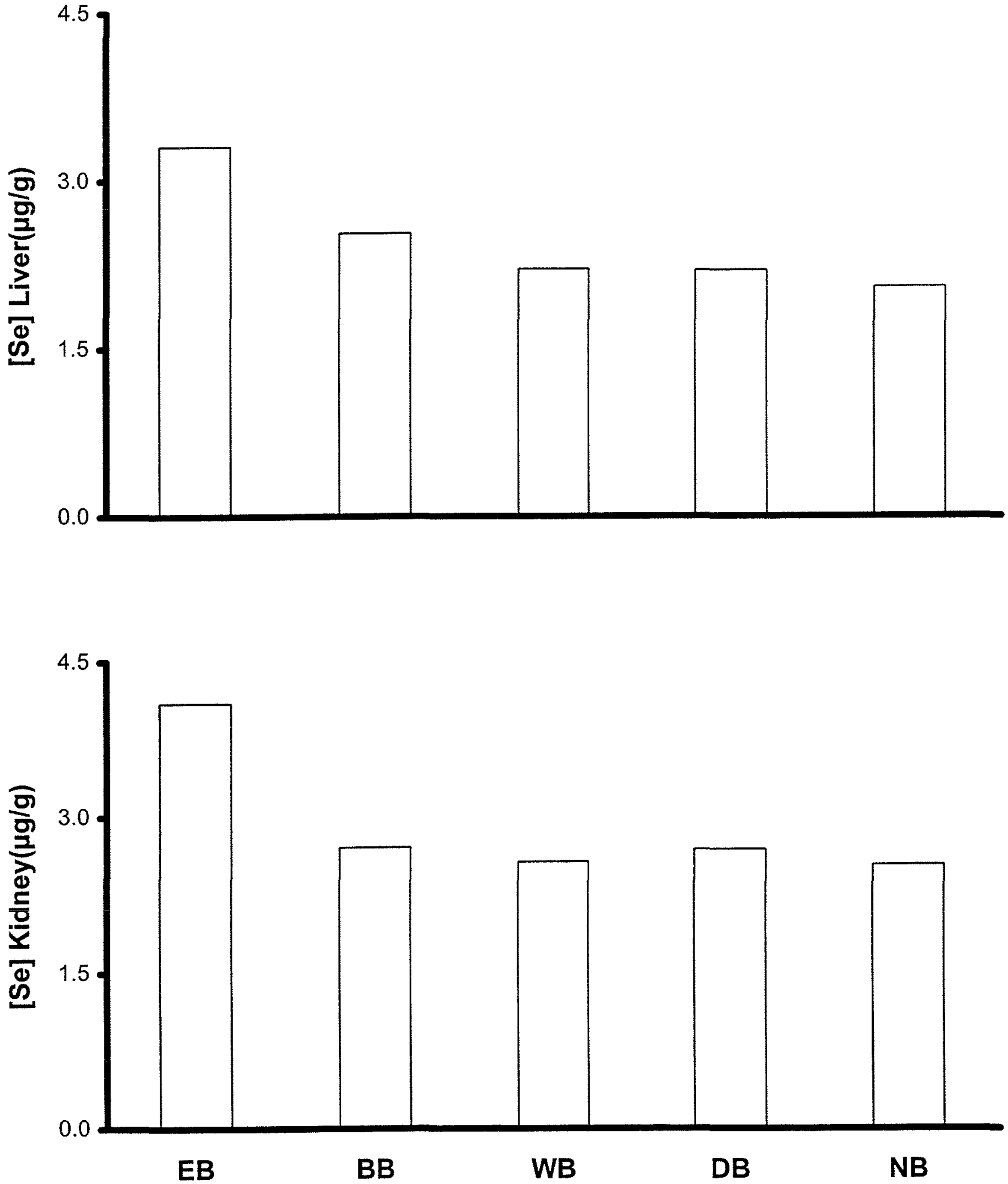

Figure 11e. Trend between Se concentration (µg/g) in liver and kidney .

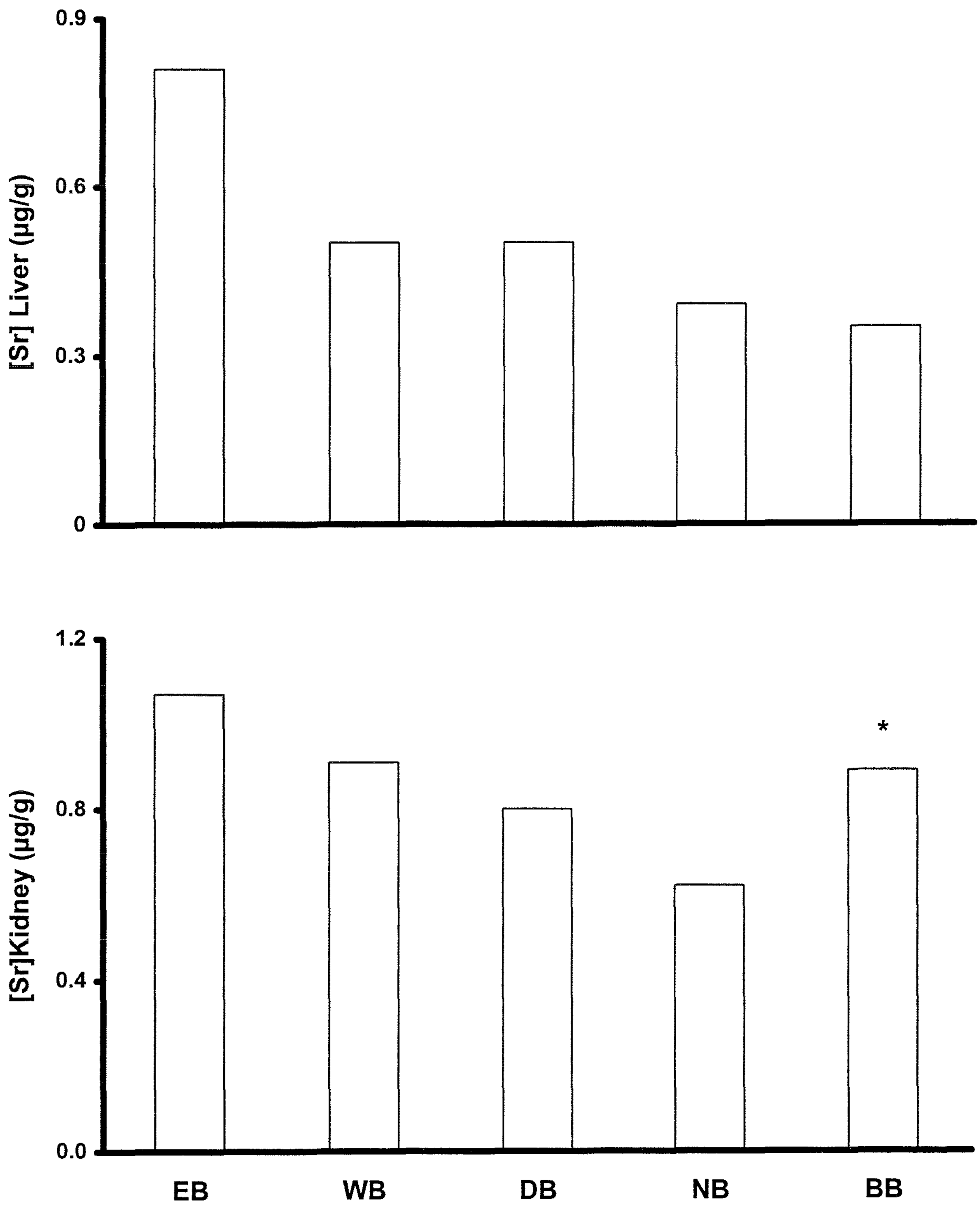

Figure 11f. Trend between Sr concentration (µg/g) in liver and kidney .

* Exception

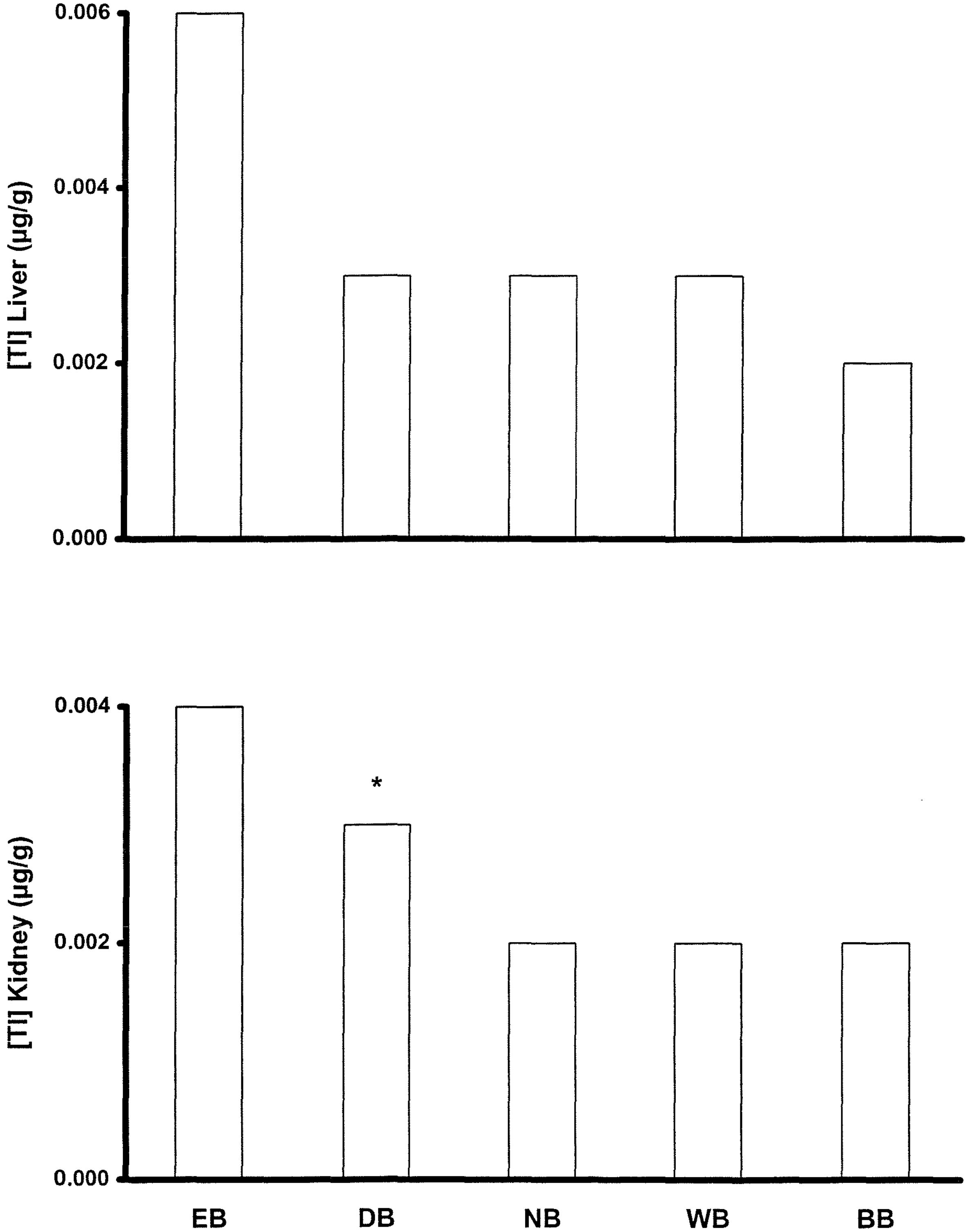

Figure 11g. Trend between Tl concentration (µg/g) in liver and kidney .

* Exception

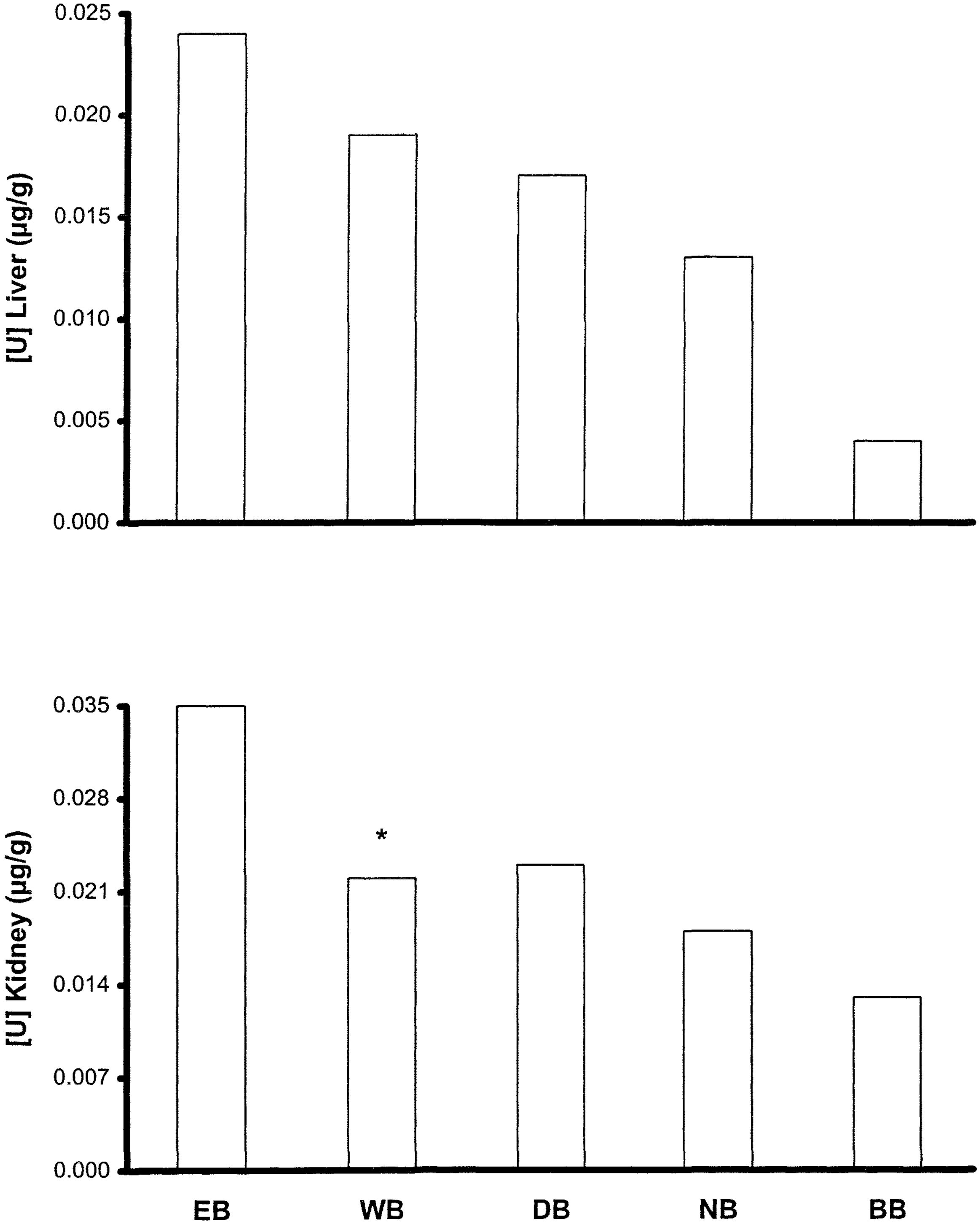

Figure 11h. Trend between U concentration (µg/g) in liver and kidney .

* Exception

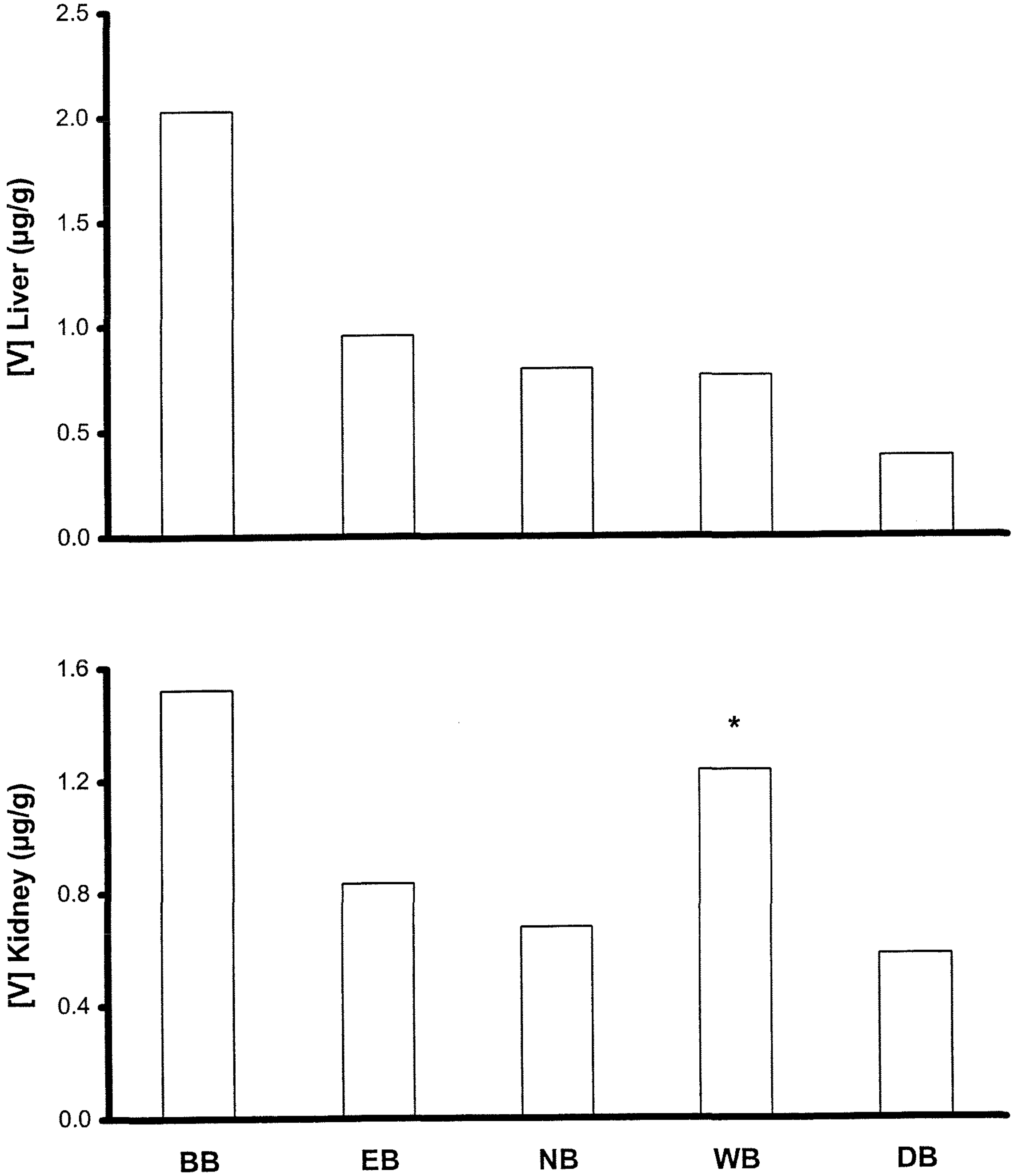

Figure 11i. Trend between V concentration (µg/g) in liver and kidney .

* Exception

3.4.3. BETWEEN TISSUES AND SEDIMENTS

Figure 12a. shows a positive trend between cadmium concentration in the liver, kidney, and sediments. The trend in Figure 12b. suggests a weak positive trend between copper in the liver and kidney with copper in sediments, although Nyanza Bay sediments have a higher copper level. Fig. 12c. shows a positive trend between manganese in the kidney and the sediments, except at Nyanza Bay, where the level is higher.

Figure 12. Trends between metal levels in liver, kidney and sediments: a) Cd in liver, kidney, sediments b) Cu in liver, kidney, sediments c) Mn in kidney and sediments

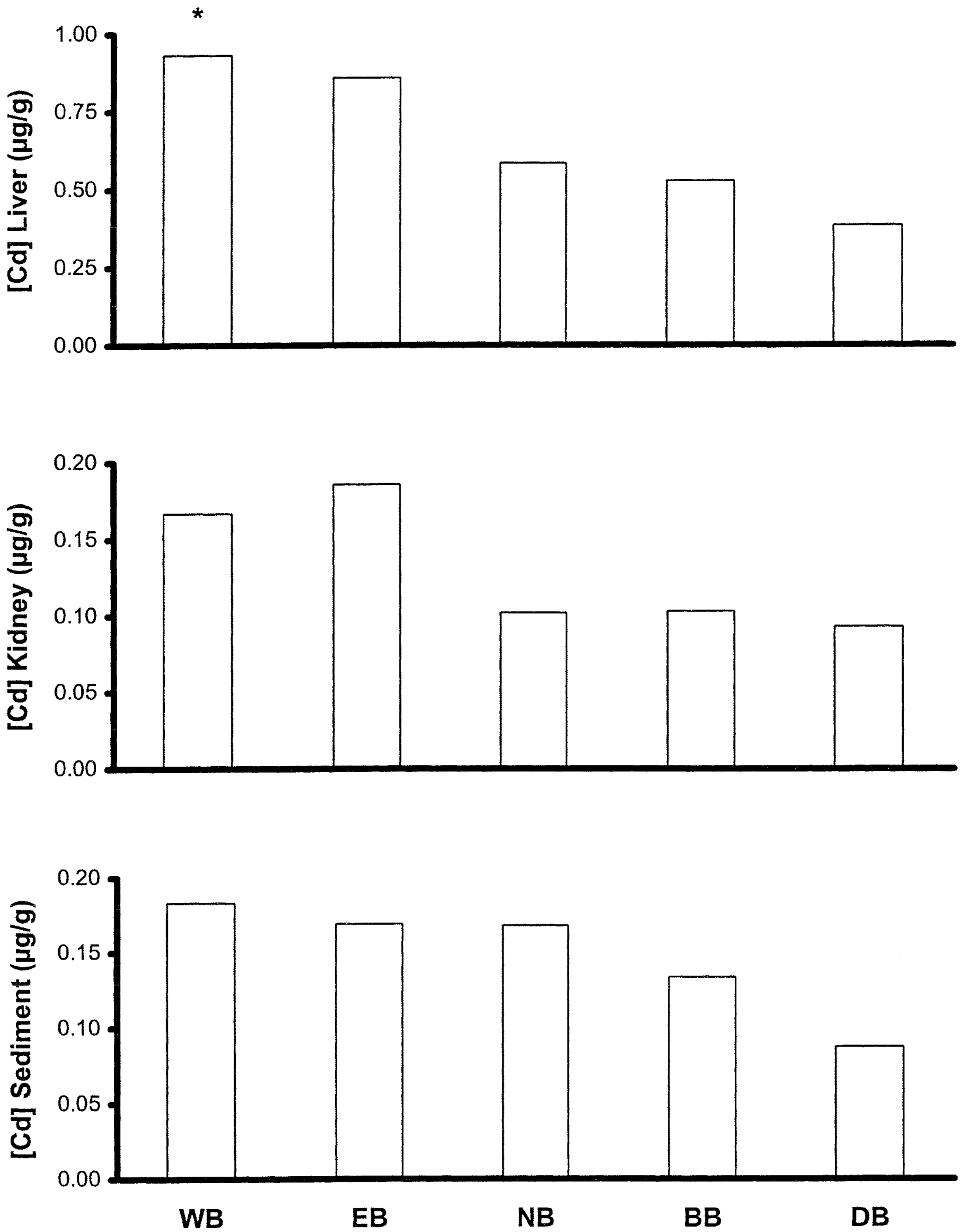

Figure 12a. Trend between Cd concentration (µg/g) in liver, kidney and sediments.

* Exception

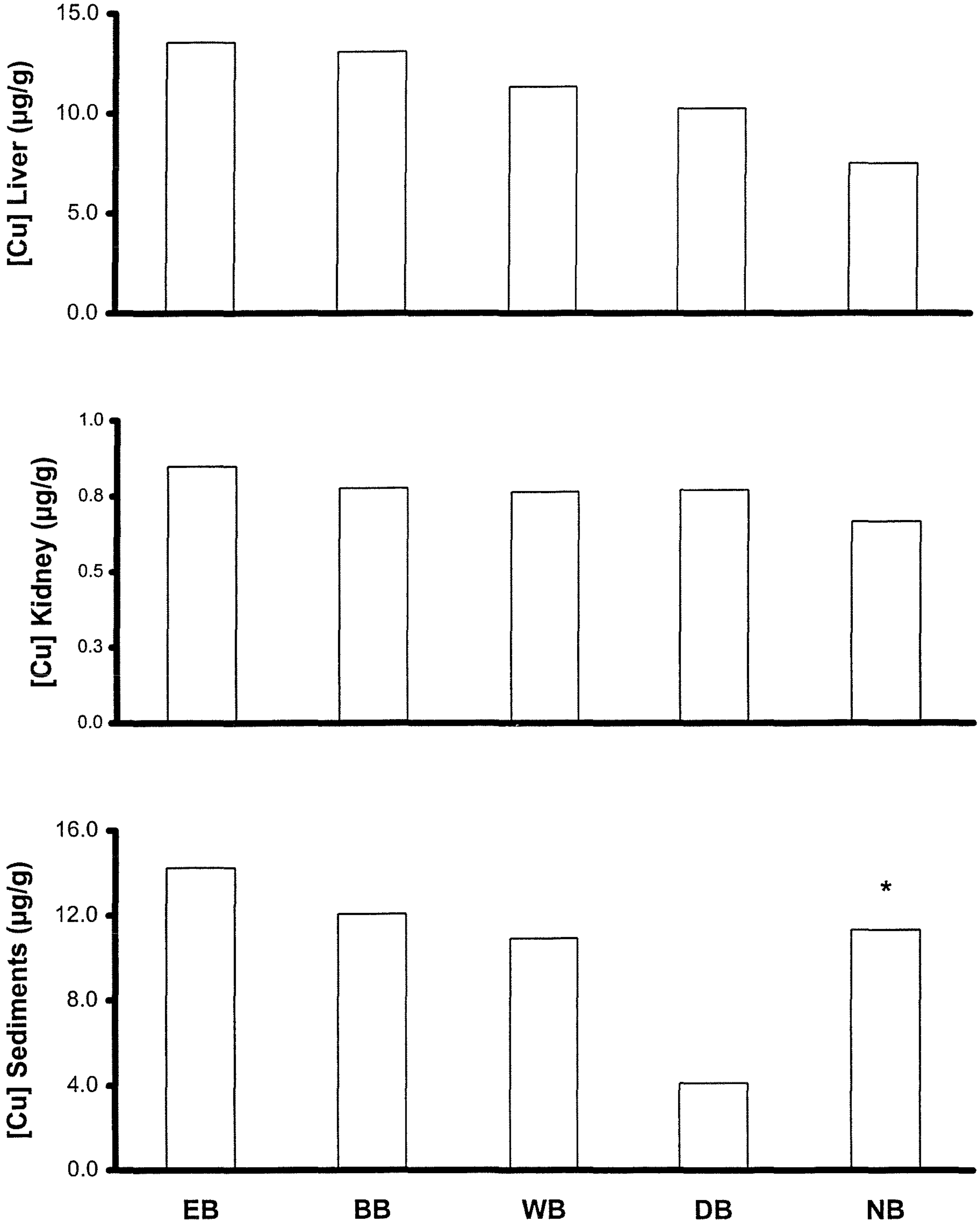

Figure 12b. Trend between Cu concentration (µg/g) in liver, kidney and sediments.

* Exception

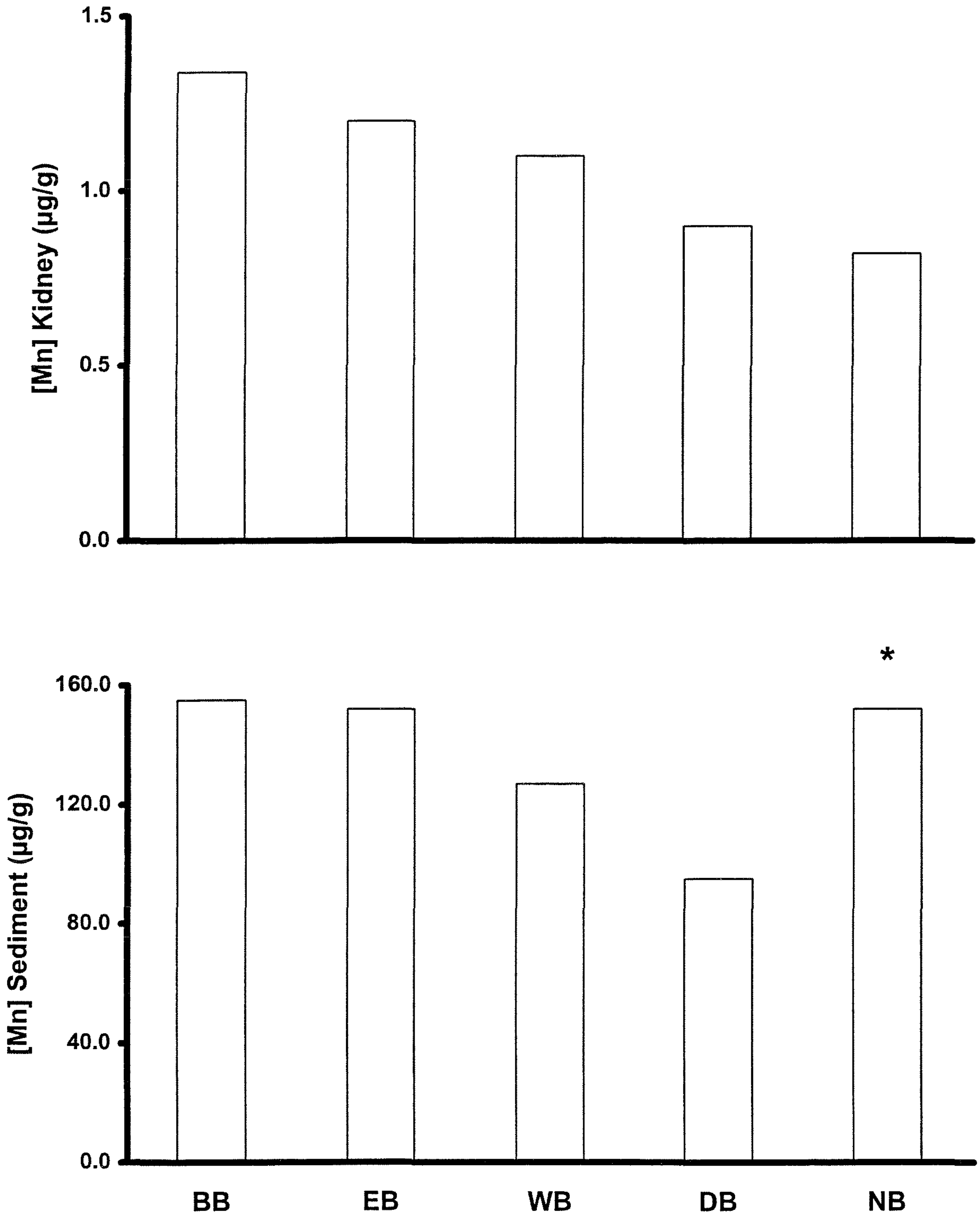

Figure 12c. Trend between Mn concentration (µg/g) in kidney and sediments.

* Exception

3.4.4. METAL INTERACTIONS

3.4.4.1. LIVER

Fig. 13a. suggests cadmium, cobalt, molybdenum and nickel are related by a positive trend in flounder liver. Fig. 13b. shows a positive trend between the concentrations of copper, manganese, selenium and silver.

Figure 13. Trends between metal concentrations (μg/g) in liver: a) Cd, Co, Mo, and Ni b) Ag, Cu, Mn and Se

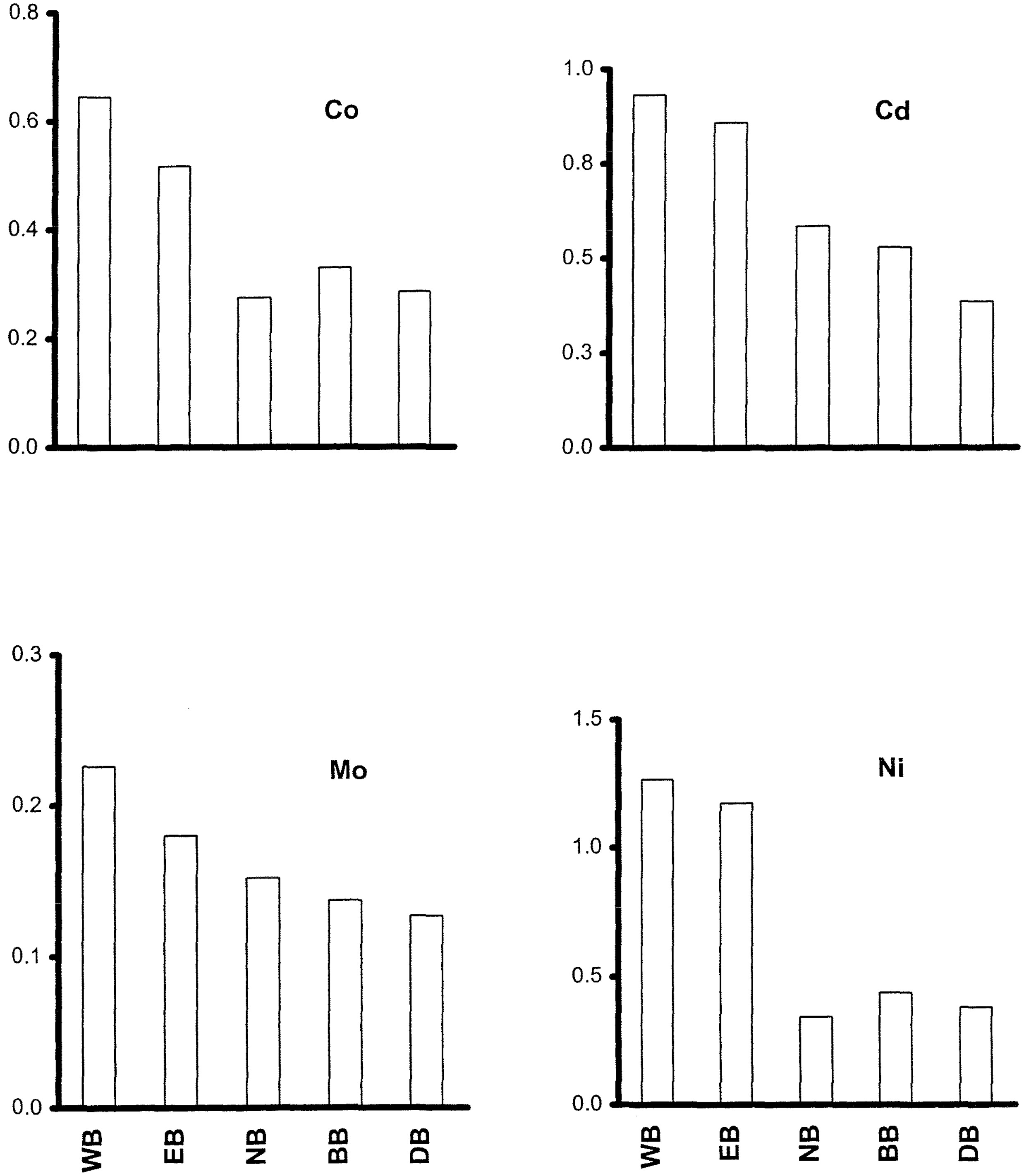

Figure 13a. Trend between Cd, Co, Mo, and Ni concentrations (µg/g) in liver.

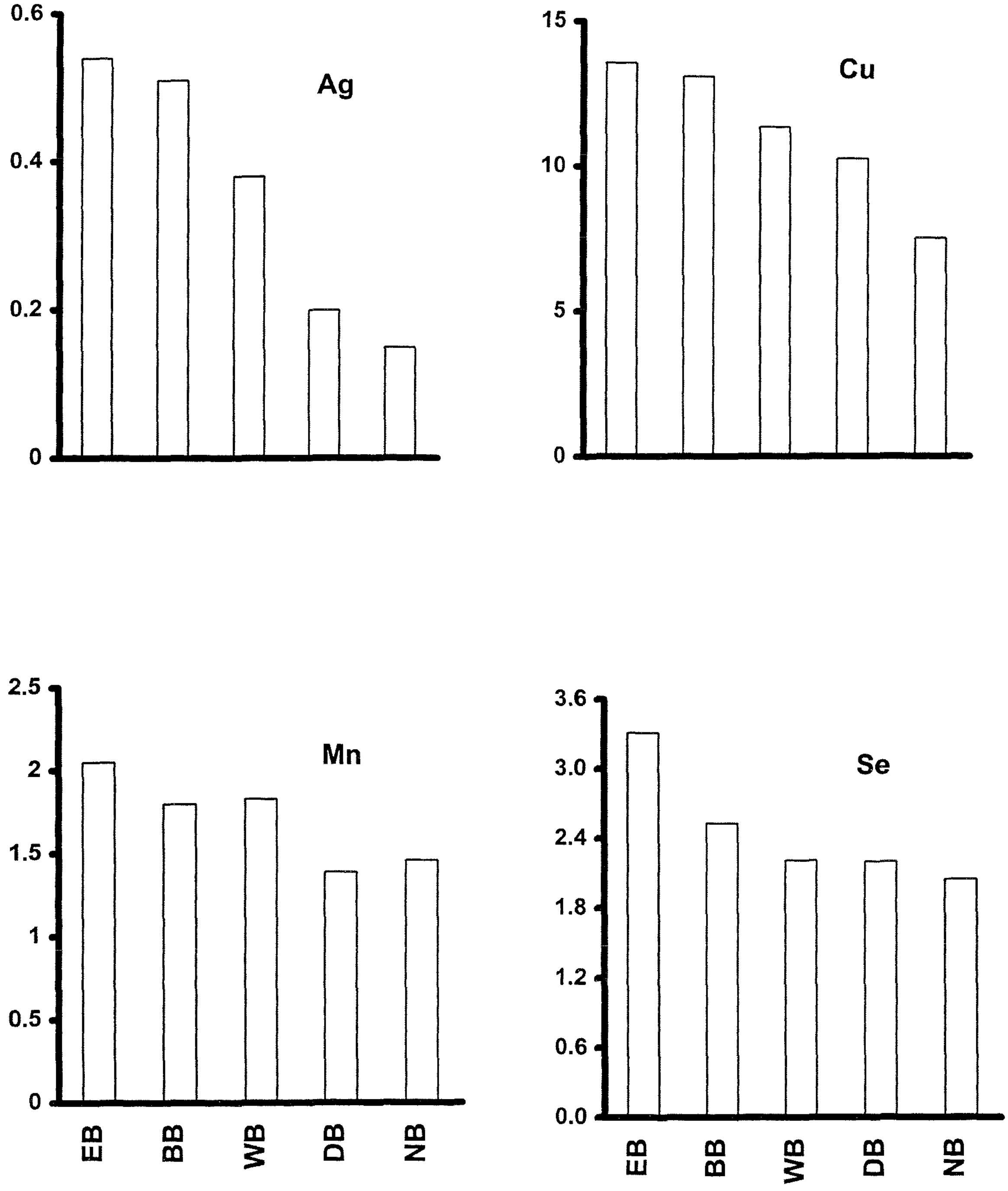

Figure 13b. Trend between Ag, Cu, Mn, and Se concentrations (μg/g) in liver.

3.4.4.2. KIDNEY

Fig. 14a. shows a positive trend between concentrations of manganese and arsenic in flounder kidney. Fig. 14b shows a positive trend between concentrations of uranium and thallium in kidney.

Figure. 14. Trends between metal concentrations (μg/g) in flounder kidney: a) As and Mn b) U and Tl

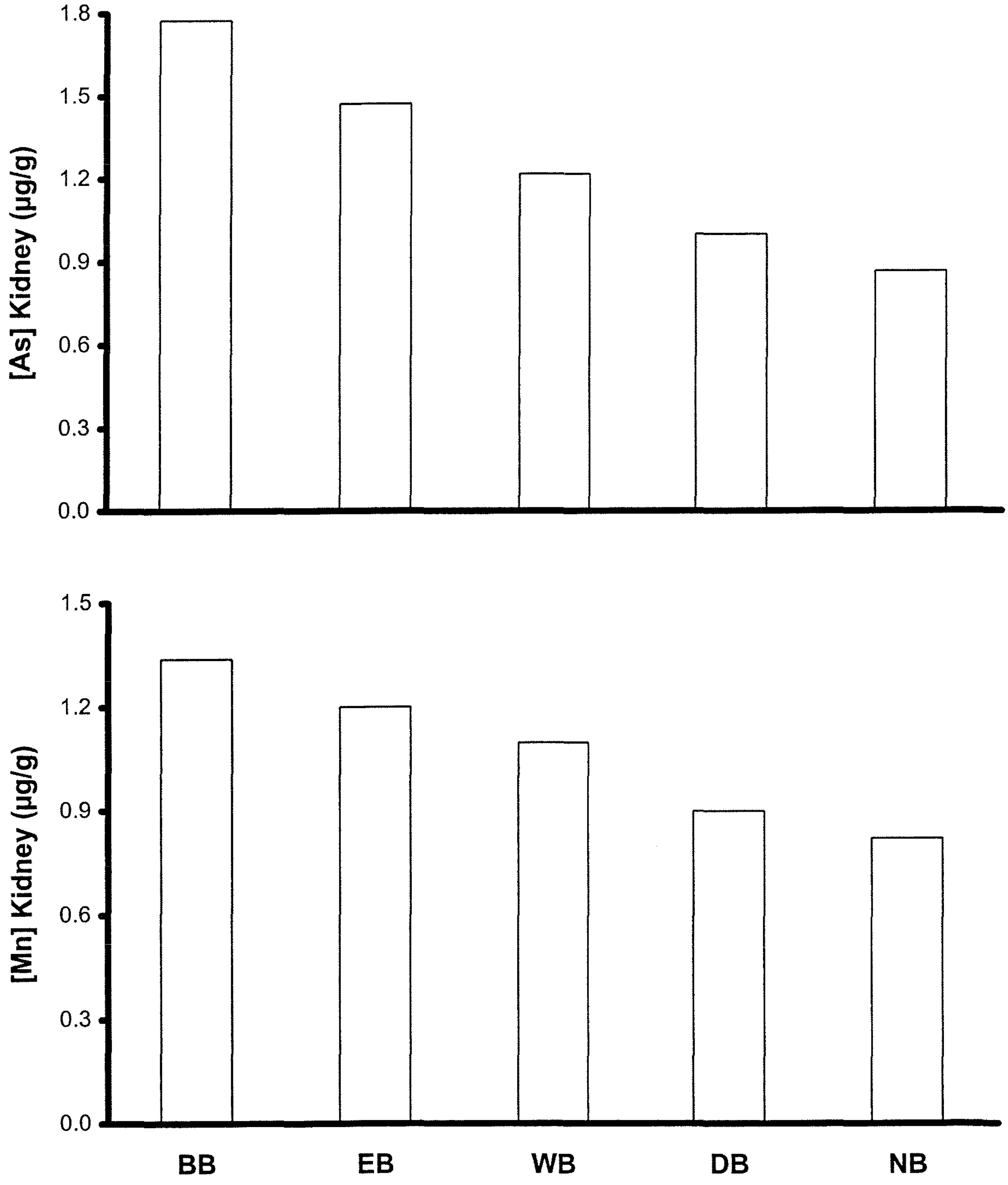

Figure 14a. Trend between As and Mn concentrations (µg/g) in kidney.

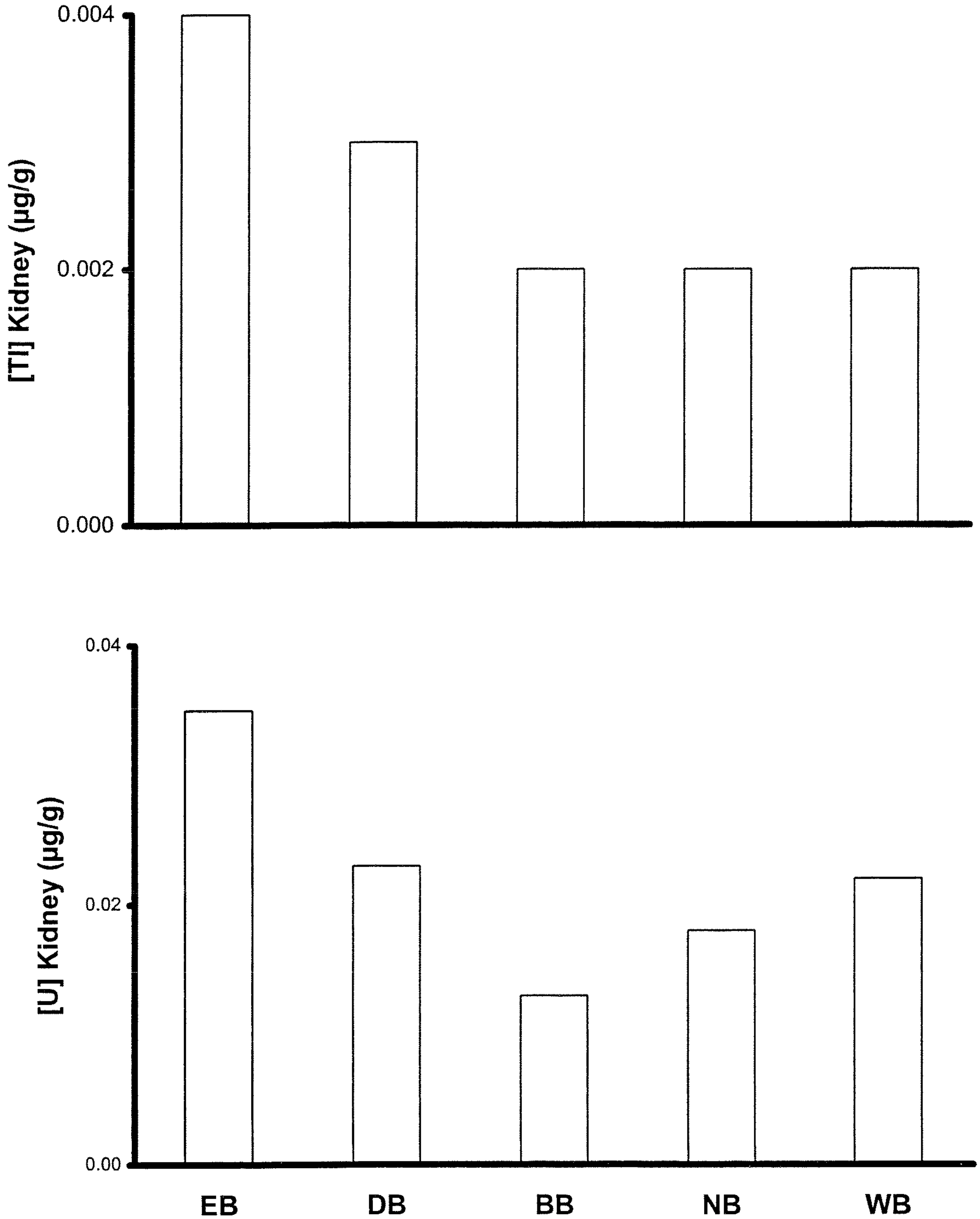

Figure 14b. Trend between U and Tl concentrations (µg/g) in kidney.

4.0. DISCUSSION

4.1. METAL LEVELS IN FLOUNDER TISSUES

Metal contamination research, has largely focused on As, Cd, Cu, Hg, Pb, and Zn (Windom *et al.*, 1973; Hardisty *et al.*, 1974; Greig and Wenzloff, 1977; and Hanson, 1997) which are often associated with industrial waste discharge and anthropogenic activity, and which can pose human health hazards. Fewer studies have investigated metals such as Be, Cr, Co, La, Mn, Mo, Sr, Tl, Ti, U, and V in fish tissue. Liver has often been a target organ because of the role it plays in the detoxification and accumulation of contaminants. Elemental levels in fish kidneys have received less attention. In the following sections, metals are discussed from highest to lowest concentrations.

4.1.1. LIVER

Zinc metal occurred in the highest concentration, by comparison with other metals. Values ranged between 37.7-44.1μg/g in Bras d'Or flounder liver. Greig and Wenzloff (1977) reported a range of 15.0-45.0μg/g wet wt. for samples collected from sites (near dredge spoils, sewage sludge, and chemical waste disposal sites, and relatively offshore sites) in the vicinity of Long Island Sound and the New York Bight. Interestingly, the authors reported that 42μg/g Zn, in flounder from a sewage disposal area in the New York Bight, varied little from the offshore station comparisons. They concluded that sewage had no demonstrable impact on Zn accumulation in winter flounder liver. In a National Marine Fisheries Service Survey, Hall *et al.* (1978), reported 30.0-40.0μg/g Zn in livers of winter flounder from the North Atlantic. For this large-scale survey, site characterizations (i.e. pollution sources, etc.) were not specified. In European flounder, *Platichthys flesus*, the overall range was 12.9-79.2μg/g Zn, whereas the mean values ranged between ~35-45μg/g wet wt. in flounder from a variety of polluted and unpolluted sites in the eastern North Atlantic (ICES, 1988). Hanson (1997) reported a range of 82-184μg/g and a mean of 116μg/g (dry wt.) in winter flounder from various harbours on the Northeast U.S. Coast.

In Bras d'Or winter flounder, liver Cu ranged from 7.51-13.6μg/g. Values in New York Bight and Long Island Sound flounder were: 2.7-13.8μg/g (Greig and Wenzloff, 1977). Other reported values were: 7.0-8.0μg/g in winter flounder collected during a survey of National Marine Fisheries Resources (Hall *et al.*, 1978), 2.8-9.1μg/g in windowpane flounder from Long Island Sound (Greig *et al*, 1983), and 2-20μg/g (wet wt.) in European flounder from a contaminated Norwegian fjord (Julshamn and Grahl-Nielsen, 1996). The results of the analyses of Cu in livers from European flounder (1.35-36.3μg/g) show the affinity of trace metals for special binding sites within liver tissue, as opposed to those of muscle (ICES, 1988). Hanson (1997) reported between 10-69μg/g (dry wt.) and a mean value of 30μg/g for Northeast Atlantic U.S. coast winter flounder.

Arsenic concentrations ranged widely in Bras d'Or flounder liver: 6.55-30.10μg/g. The highest concentration, in East Bay flounder, was about 5 times the concentration in Denys Basin flounder, and may reflect higher levels of environmental As at East Bay, although it is unclear whether this is due to a natural or anthropogenic source. In flounder collected from Baddeck Bay, which is near a more highly populated community, As concentration was 15.77µg/g. Arsenic concentration was 5-6µg/g (wet wt.) in liver of winter flounder collected for a U.S. National Fisheries Survey of Marine Resources, however site characteristics were not specified (Hall *et al.*, 1978). Much lower As values were reported for the European flounder (0.2 and 0.47µg/g (wet wt.)) collected at a variety of sites throughout the eastern North Atlantic (ICES, 1988). By comparison, Windom *et al.* (1973) reported a range of 6-44µg/g (dry wt.) in a variety of inshore fish species.

Liver selenium ranged between 2.05-3.31µg/g in Bras d'Or samples. Hall *et al.* (1978) reported 2.0-3.0µg/g (wet wt.) Se in flounder collected from 198 sites around coastal United States. Hanson (1997) reported a mean of 6.2µg/g (dry wt.) Se and a range of 2.8-13µg/g, in a multi-year study of winter flounder from 23 sites along the northeast Atlantic coast where concentration of habitat contaminants varied from nil to levels signifying important anthropogenic inputs.

Manganese concentrations in liver of Bras d'Or flounder were 1.39-2.05µg/g. 0.9-1.8µg/g were found in winter flounder from Long Island Sound, but Mn concentrations were more elevated in flounder collected from sites that were considered to be less polluted (based on metals in sediments) (Greig and Wenzloff, 1977). In the same study, 0.3-2.5µg/g Mn (wet wt.) were reported in winter flounder from the New York Bight, and Mn did not seem to vary in any systematic way with respect to pollution. Hall *et al.* (1978) reported 0.8-0.9µg/g Mn in liver of North Atlantic flounder, but did not specify charactizations of catch locations. Hanson (1997) reported a range of 1.2-12µg/g, and a mean of 4.8µg/g (dry wt.) in winter flounder collected between 1984 and 1989 from various sites along the northeast Atlantic coast of the U.S.

Silver concentrations varied between 0.15-0.54µg/g in Bras d'Or flounder liver. The same species from New York Bight and Long Island Sound had concentrations of <0.1-0.8µg/g (wet wt.) (Greig and Wenzloff, 1977), which were comparable in yellowtail flounder from the same areas. Samples from the Bight's sewage sludge disposal area (Station 8) had concentrations <0.1µg/g Ag in liver. In a large-scale study of the coastal resources of the U.S., Hall *et al.* (1978) reported <0.1µg/g in winter flounder from the North Atlantic. Hanson (1997) reported 0.16-2.0µg/g (dry wt.) with a mean of 0.89µg/g for various sites along the northeast coast of the U.S.

By comparison with the metals discussed in the previous paragraphs, concentrations of Ni, V, Cd, Sr, Cr, Ti, Co, and Mo were generally in the range of 0.2-1.0µg/g in Bras d'Or flounder liver.

Liver nickel varied between 0.34-1.27µg/g (wet wt.). Whycocomagh (1.27µg/g) and East Bay (1.17µg/g) samples had more elevated levels, compared to Nyanza Bay (0.34µg/g) and Denys Basin (0.38µg/g). Baddeck Bay samples had a concentration of (0.44µg/g). Ni concentrations were comparable in flounder collected from 2 sites: polluted and less polluted, in Long Island Sound (0.3µg/g wet wt.) (Greig and Wenzloff, 1977). In the same study, the authors reported a range of <0.3-<1.0µg/g Ni (wet wt.) in finfish from the New York Bight. Hanson

(1997) reported a mean of 0.33µg/g Ni (dry wt.) (range: 0.05-1.04µg/g) in winter flounder collected at 44 sites along the U.S. Atlantic seaboard. Flounder from various locations in the U.S. Atlantic contained 0.2-0.3µg/g (wet wt.) Ni (Hall *et al.*, 1978). A much higher mean concentration of 10.8µg/g (wet wt.) was reported in plaice from heavily polluted inshore waters around Lynemouth, Northumberland, U.K. (Wright, 1976).

In Bras d'Or flounder, liver cadmium was 0.39-0.93µg/g. Greig and Wenzloff (1977) reported a concentration of <0.1µg/g Cd (wet wt.) in liver of winter flounder from Station 1, heavily polluted based on sediment metals, and by comparison with Station 3, also in Long Island Sound. Flounder collected at the latter station contained 0.28µg/g Cd in liver tissue. At Station 8, the New York Bight's sewage disposal site, Cd concentration was <0.2µg/g. Hall *et al.* (1978) reported a Cd liver range of <DL to 0.300µg/g. In a baseline study of European flounder, values ranged widely between <0.002-0.9µg/g (wet wt.) (ICES, 1988). Hanson (1997) reported a range of 0.08-2.0µg/g Cd (dry wt.) (mean=0.57µg/g) in winter flounder from 44 sites along northeastern U.S. More elevated values, 2.91µg/g (wet wt.), were found in plaice from polluted (coal and aluminum industry) inshore waters off the north-east coast of England, (Wright, 1976).

Liver chromium ranged between 0.59-0.72µg/g in Bras d'Or flounder. Greig and Wenzloff (1977) reported a mean concentration of 0.5 µg/g (wet wt.) in winter flounder from various sites in Long Island Sound and the New York Bight, and a range of 0.1-0.6µg/g in yellowtail flounder. Of this range, <0.2µg/g occurred in fish from the Bight's sewage sludge disposal area. In a National Marine Fisheries Board survey of U.S. coastal resources, Hall *et al.* (1978) reported a range of 0.060-0.110µg/g (wet wt.) chromium in flounder liver. Site characterizations were not specified.

In Bras d'Or flounder liver, Mo ranged from 0.13-0.23µg/g (wet wt.). Flounder from Whycocomagh Bay had the highest Mo levels. These values were lower than those reported by Hall *et al.* (1978) for flounder collected for a survey of National Marine Fisheries Resources: overall range of 0.190-0.410µg/g and mean range of 0.3-0.4µg/g.

Lead concentrations in Bras d'Or Lake flounder liver ranged widely (0.01-0.16µg/g). Highest concentration occurred in Baddeck Bay samples, and lowest were in Denys Basin samples. Winter flounder from New York Bight and Long Island Sound had liver Pb between <0.6-1.5µg/g (wet wt.) (Greig and Wenzloff, 1977). Lead concentrations were similar in samples collected from both polluted and unpolluted sites in Long Island Sound. Hall *et al.* (1978) reported a mean range of 0.9-1.0µg/g (wet wt.) in a survey of U.S.National Marine Fisheries Resources. Site characteristics were not specified. In European flounder collected from coastal waters of the North and Baltic Sea, the overall range for all sites was 0.01-0.16µg/g (wet wt.) (Luckas, 1987). A range of 0.0211-0.820µg/g was reported for European flounder (ICES, 1988), and Hanson (1997) reported a range of 0.28-7.4µg/g (dry wt.) and a mean of 1.4µg/g (dry wt.) in liver of winter flounder from various harbours in the northeastern U.S.

Cobalt concentrations in Bras d'Or flounder were 0.28-0.65µg/g. Pentreath (1973a) investigated the accumulation and retention of ^{58}Co by the plaice, *Pleuronectes platessa* L., and reported a liver tissue value of 0.49µg/g (wet. wt.) in the stable form.

Vanadium ranged from 0.38-2.03µg/g; strontium from 0.35-0.81µg/g; titanium from 0.22-0.39µg/g; lithium from 0.05-0.07µg/g; beryllium from 0.01-0.05µg/g; uranium from 0.004-0.024µg/g; thallium from 0.002-0.006µg/g and lanthanum from undetected-0.024µg/g. The latter five elements were minor constituents in flounder liver (ppb levels), and may simply reflect background levels in the environment. In the literature, Tl concentration was reported for flounder eggs (Vitaliano and Zdanowicz, 1992). Hellou *et al.* (1996) reported <0.5µg/g Li and 3.5µg/g V (dry wt.) in females and <0.5µg/g V in the liver of male yellowtail flounder, *Pleuronectes ferruginea,* collected off the coast of Newfoundland. In the same study, Be and La were below the detection limit of 0.05µg/g (dry wt.). In the literature, Sr concentration was reported in liver of the thornback ray, *Raia clavata* L., in the Irish Sea: 0.647 ±0.016µµc/g Sr^{90} wet wt. was found in the tissues of rays from the end of a pipeline (Mauchline and Taylor, 1964). No information was found in the literature regarding Ti, Tl and U in flounder liver.

In general, most metallic levels in Bras d'Or flounder liver are comparable with those available in the literature, although it was not always possible to identify the characteristics of the areas from which the fish were collected. Silver was slightly elevated in Bras d'Or samples, even by comparison with samples from Long Island Sound. Cd seemed slightly elevated compared with North Atlantic flounder samples, but were lower compared with European flounder from a highly polluted area off the North East coast of England. Arsenic results ranged widely, and such wide variation was also observed in the literature. (Ti, and U concentrations were not available in the literature for fish tissue, and Co and Sr were only reported for radionuclide studies.) Wide variation in liver metal concentrations were observed for As, Cu, Ni, and Pb, and may suggest that, for these metals, the liver is a good indicator of environmental levels.

4.1.2. KIDNEY

According to Dallinger *et al.* (1987) the kidney and the liver are targets for final deposition of a variety of metals in marine organisms. In general, in marine fish, liver is investigated for metal contamination, rather than the kidney. By contrast, levels in freshwater species are more commonly available for the kidney (Camusso *et al.*, 1995; Wood *et al.*, 1996; Kock *et al.*, 1998; Yamazaki *et al.*, 1996). Since metal contents in flounder kidneys are rarely reported in the literature, comparisons with other marine fish such as plaice, dab, etc. are drawn in the following discussion. As in the liver section, metals in Bras d'Or flounder kidney will be discussed in descending order by concentration, and compared with literature values.

In Bras d'Or flounder kidney, zinc was in the highest concentration (26.3-33.1µg/g wet wt.), and was only slightly lower than the liver value. In the kidney of dab (*Pleuronectes*) sampled from industrial areas along the North East Coast (England), a concentration of 47.6µg/g Zn was reported (Wright, 1976). Hardisty *et al.* (1974) reported Zn concentrations as high as

300-420μg/g (dry wt.) in European flounder collected from sites located various distances from pollution discharge sources in the Severn Estuary, U.K. Windom *et al.* (1973) reported 25μg/g (dry wt.) in off-shore North Atlantic finfish species. Protasowicki (1992) reported 52.26-169.23μg/g Zn (dry wt.) in kidneys of dab from 6 sites in German Bight (site descriptions were not included).

Selenium was the second most abundant element in flounder kidney, at all sites (2.54-4.10μg/g). Selenium has received wide attention because the concentration is highly correlated with Hg levels in various species, and a detoxification role is suspected (Brown and Depledge, 1998). A significant correlation was noted between mercury and selenium and both of these elements were correlated with fish size, in the black marlin off north-eastern Australia (MacKay *et al.*, 1975).

Arsenic in the kidney ranged from 0.87-1.78μg/g (difference of a factor of 2), and was lower than liver values.

Manganese ranged from 0.82-1.34μg/g. Pentreath (1973b) reported 0.72μg Mn/g in the kidney of plaice, *Pleuronectes platessa* L. and 1.95μg Mn/g in the kidney of *Raia clavata,* a ray species (1973c).

V ranged from 0.58-1.52μg/g and Sr from 0.62-1.07μg/g. No information was available in the literature.

Nickel ranged from 0.62-1.12μg/g. Wright (1976) reported kidney levels of 6.0 and 2.0μg Ni /g (wet wt.) in plaice and dab, respectively, collected from heavily polluted inshore waters around Lynemouth in Northumberland, U.K.

Copper concentration ranged from 0.67-0.85μg/g. Wright (1976) analyzed Cu in the kidneys of fish from polluted inshore waters around Lynemouth in Northumberland, U.K. 1.2μg/g Cu were reported for the kidneys of the lumpsucker (*Cyclopterus lumpus).* Protasowicki (1992) reported 0.85-4.04μg/g Cu (dry wt.) in the kidneys of dab, *Limanda limanda*, from the German Bight transect. In *Carcharhinus falciformis*, a finfish species from the North Atlantic, a mean of 5.7μg/g Cu (dry wt.) was reported (Windom *et al.*, 1973).

Chromium concentrations ranged between 0.58-0.73μg/g; titanium between 0.28-0.37μg/g; and cobalt between 0.11-0.22μg/g. Cobalt was not detected in the kidney of plaice (Pentreath, 1973a).

Cadmium in Bras d'Or flounder kidney ranged between 0.09-0.19μg/g. Wright (1976) reported 0.21μg/g (wet wt.) Cd in kidneys of dab from polluted inshore waters, around Lynemouth in Northumberland, U.K. Protasowicki (1992) reported concentrations from undetected to 0.399μg/g Cd (dry wt.) in the same species from the German Bight transect. The characterizations of the sites were not available (i.e. polluted or not). Windom *et al.* (1973) reported 2.6μg/g (dry weight) Cd in a finfish species (*Carcharhinus falciformis*) from the North Atlantic. In another study, sea bass (*Dicentrarchus labrax*) were exposed to two different cadmium (0.5 and 5.0μg/mL) concentrations in seawater (Cattani *et al.*, 1996). After 170 hours, 4μg/g and 30μg/g accumulated in the kidney of fish exposed to 0.5 and 5.0μg Cd/mL in seawater, respectively. Overnell and Abdullah (1988) reported a range of 0.6-0.9μg/g Cd (dry wt.) in the kidney of the European flounder from 4 field sites in Langesundfjord, Norway, that were subject to a pollution gradient.

Lead ranged from 0.01-0.09μg/g (wet wt.) in the kidney of Bras d'Or flounder. Protasowicki (1992) reported 1.63-3.85μg/g (dry wt.) Pb in the kidney of dab from the German Bight. European flounder (*Platichthys flesus*) from the Severn Estuary (U.K.), known to have elevated levels of Pb, Cd and Zn, had 20-30μg/g Pb (dry wt.) in kidney tissue (Hardisty *et al.*, 1974).

Lower concentrations were determined for Li (0.08-0.10μg/g), Mo (0.05-0.09μg/g), Be (0.05-0.06μg/g), U (0.013-0.035μg/g) and Tl (0.002-0.004μg/g). Silver was not detected.

Kidney concentrations for Ag, As, Be, Cd, Co, Cu, Cr, Li, Mn, Mo, Ni, Pb, Se, Sr, Ti, Tl, U, V, and Zn were presented in comparison with the liver to aid in the understanding of metal accumulation in this species, and to provide background levels. Cd, Co, Cu, Mn, Ni, Se, and Zn concentrations in Bras d'Or flounder were comparable or lower than levels reported elsewhere for other fish species.

4.1.3. SEDIMENT

Sediment concentrations are discussed from highest to lowest concentration in the sediments, reported as dry weight (μg/g).

In Bras d'Or sediments, titanium occurred in the highest concentrations (789-1750μg/g). As part of an ICES baseline study, surface sediments (0.1cm) in the Gulf of Finland, the Bothnian Bay, and the Bothnian Sea were collected, and mean Ti concentrations of 3940, 3420, and 3880μg/g dry wt., respectively, were reported (Leivuori, 1998). Concentrations as high as 5420μg/g (in deeper core sediments) and as low as 3420μg/g Ti were reported. The highest concentrations were reportedly from easternmost regions of the Gulf of Finland, primarily due to the industrial area of St. Petersburg.

Manganese was the second most abundant element (95-155μg/g). At most sites, Mn was in the range of 150μg/g, except at Denys Basin (95μg/g). Greater Mn levels have been reported elsewhere in Nova Scotia (431-732μg/g) (Loring *et al.*, 1996); 193.5μg/g in sediments from Grand Desert Beach, N.S., a non-industrialized control sediment and in sediments from Dalhousie (214μg/g) and Belledune, N.B. (244.5μg/g), 2 contaminated sites (Samant, 1990). In Long Island Sound, concentrations between 12.0-1218.0μg/g were reported (Greig *et al.*, 1977).

Nickel values ranged between 12.7-110μg/g. At 4 of 5 Bras d'Or sample sites, sediment concentrations (>70μg/g) surpass the maximum (27μg/g) reported by Loring *et al.* (1996) for Nova Scotian harbours, by at least a factor of 2.5. Nickel ranged from 7.5μg/g at Grand Desert Beach, Nova Scotia (non-industrialized) (Samant, 1990); 10-25μg/g at the cleanest sample site in a Long Island Sound study (Gronlund *et al.*, 1991); <2.0-41.6µg/g at over 100 sites in Long Island Sound (Greig *et al*, 1975); and 19.7-71.4µg/g with a mean value of 28.0µg/g in the Gulf of Maine (Larsen and Gaudette, 1995).

Vanadium ranged between 20.4-60.4µg/g, and was between 54-60.4 µg/g at 4 of 5 sites, except Denys Basin. Loring *et. al.* (1996) reported 27-86µg/g in the sediments from 10 Nova Scotia harbours, and Samant (1990) found 14.7µg/g in sediments from Grand Desert Beach, a non-industrialized site; 27.4 at Dalhousie and 44.3µg/g at Belledune, both contaminated sites in New Brunswick. Chester (1975) reported a concentration range of 37-130µg/g V in sediments from polluted areas in the Lower Severn Estuary and Bristol Channel.

Zinc ranged from 21.8-57.8µg/g, and was lowest at Denys Basin. The other 4 sites ranged between 47.7-57.8µg/g. Values range within 10 µg/g, except at Denys Basin, where the concentration is lower. In a survey carried out by Loring *et al.*(1996), concentrations between 39-96µg/g were determined in sediments collected from a variety of harbours around Nova Scotia, and a background level of 150µg/g was reported. Whereas, Chester (1975) found 80-110µg/g in "unpolluted" sites in the Lower Severn Estuary and the Bristol Channel. Gronlund *et al.* (1991) determined that the concentration of zinc in sediments from Niantic Bay, one of the cleaner sites in a Long Island Sound Survey, fell between 40-110µg/g, and Larsen and Gaudette (1995) reported a mean of 111.32µg/g with a range of 61.6-286.8µg/g for 41 samples from a variety of harbours in the Gulf of Maine. Greig *et al.* (1977) reported a value range of 2.3-354.0µg/g in over 100 samples from Long Island Sound.

Lithium ranged between 11.5-47.3µg/g and were comparable to other Nova Scotia harbours (22-56µg/g) (Loring *et al.*, 1996).

Chromium ranged from 11.3-42.1µg/g. Loring *et al.*(1996) reported a higher concentration range, of 28-83µg/g in sediments from a variety of Nova Scotia harbours. Gronlund *et al.* (1991) determined a range of 30-80µg/g for one of the cleaner sites in Long Island Sound Greig *et al.* (1977) reported values as low as 2.9µg/g and as high as 162.7µg/g in sediments from over 100 sites in Long Island Sound.

Strontium ranged from 8.37-26.1µg/g. Samant (1990) reported a concentration of 25.3µg/g in Grand Desert Beach sediments (an unpolluted site), and 70.3µg/g (Dalhousie, N.B.), and 194.1µg/g (Belledune, N.B.). The Bras d'Or values are lower than the 95-149µg/g reported by Loring *et al.* (1996) in sediments from 10 harbours around Nova Scotia. These are lower than the range reported for sites in the Bristol Channel: 130-250µg/g (Chester, 1975), which were considered "unpolluted" at the time of the study.

Copper ranged between 4.13-14.3µg/g. ~7-58µg/g were reported by Loring *et al.* (1996) for 10 N.S. harbours, with a background level of ~40µg/g. Levels at other sites in Maritime Canada include: 25.3µg/g at Grand Desert Beach, N.S., 7.3µg/g at Dalhousie, N.B. and 194.1µg/g at Belledune, N.B. The latter 2 are known to be contaminated. Skei *et al.* (1972) determined values of 210-1200µg/g in sediments from polluted areas at Sorfjord, West Norway; Greig *et al.*(1977) reported 269µg/g in sediment from an area of known discharge in Long Island

Sound. Larsen and Gaudette (1996) reported 15.1-215.5μg/g and a mean of 34.8μg/g in Gulf of Maine samples and Chester (1975) reported 10-78μg/g for sites in the Lower Severn Estuary and the Bristol Channel.

3.51-8.86μg/g Pb were reported in Bras d'Or sediments. Loring *et al.* (1996) reported 15-45μg/g for Nova Scotia harbours and background levels of 40μg/g. Samant (1990) reported 5.4μg/g, 519.5μg/g and 1638μg/g Pb in sediments from Grand Desert Beach, N.S., Dalhousie, N.B., and Belledune, N.B., respectively. Chester (1975) reported a wide range of lead concentrations in sediments from the Lower Severn Estuary and Bristol Channel (undetected - 25μg/g); sediments from least contaminated sample sites in Long Island Sound had 0-30μg/g (Gronlund *et. al.*, 1991); and Zdanowicz *et al.* (1986) reported 20μg/g at the 2 sites sampled in Long Island Sound. Larsen and Gaudette (1995) reported a concentration range of 10.4-210.1μg/g with a mean of 37.7μg/g in Gulf of Maine sediments and concentrations as high as 210μg/g have been reported elsewhere (Greig *et al.*, 1977).

Arsenic ranged between 2.22-9.08μg/g. Loring *et al.* (1996) reported a range of 4-22μg/g for 10 diverse harbours around Nova Scotia, Canada and background levels of 20μg/g.

Cobalt concentration was 2.56-7.07μg/g. Loring *et al.* (1996) reported 3-9μg/g for 10 harbours around Nova Scotia. Samant (1990) reported a concentration of 4.3μg/g at control site at Grand Desert Beach, N.S., compared with 8.7μg/g (Dalhousie, N.B.) and 12.3μg/g (Belledune Harbour, N.B.). Chester (1975) reported a higher range (8-22μg/g) for sediments collected from "unpolluted"sites in the Severn Estuary and the Bristol Channel (U.K.). Whereas, Greig *et al.* (1977) found that sediments from Long Island Sound, a known-polluted site, contained a range of 0.5-14.8μg/g cobalt.

Selenium ranged from 1.82-7.92μg/g. Uranium ranged between 1.03-2.80μg/g. This range is consistent with values from 10 sites around Nova Scotia (1.0-3.6μg/g) (Loring *et al.*, 1996).

Molybdenum ranged widely between 0.34-2.64μg/g. The concentrations found in Bras d'Or Lake sediments were lower than those reported for Nova Scotia harbours (<2-9μg/g) (Loring *et al.*, 1996).

Beryllium ranged between 0.82-2.08μg/g. Loring *et al.* (1996) analyzed beryllium, but all samples were below the detection limit of 5μg/g.

Silver ranged from undetectable at Denys Basin to a maximum of 0.087μg/g. In clean areas in estuaries of the eastern U.S., values were <0.3μg/g (Zdanowicz *et al.*, 1986). Much higher concentrations were reported for sediments from Sorfjord, West Norway (13-190μg/g) (Skei *et al.*, 1972).

Lanthanum ranged from 0.57-0.85μg/g. Antimony ranged from (0.35-0.65μg/g) and fell within the range of sediment values (0.5-0.8μg/g) (dry wt.), determined in sediments from the most contaminated site (New Haven), in Long Island Sound, New York (Gronlund *et al.*, 1991).

Concentrations for the least contaminated site (Niantic Bay) were only slightly lower: 0.3-0.5μg/g (dry wt.). Thallium concentration ranged between 0.16-0.32μg/g.

Cadmium ranged by a factor of 2 times, between 0.09-0.18μg/g, and were lower than all other elements analysed in the sediments. Generally, Bras d'Or Cd values were lower than those reported in the literature, for other areas. Loring *et al.* (1996) found a range of 0.05-1.3μg/g cadmium in sediments from harbours around Nova Scotia, and reported background levels of 0.3μg/g. Samant (1990) determined concentrations of 0.2μg/g at Grand Desert Beach, N.S. (uncontaminated), 1.0 (Dalhousie, N.B.), and 43.6μg/g at Belledune, N.B. Zdanowicz *et al.* (1986) found values between 0.2-0.3μg/g in control sites for a study of the eastern seaboard of the U.S. Larsen and Gaudette (1995) found a mean As concentration of 0.76μg/g and an overall range of 0.23-2.60μg/g in 41 sediment samples collected in the Gulf of Maine.

Generally Bras d'Or Lake sediment metal concentrations were lower or comparable with literature values, and site characteristics were specified when possible. Ni was the only metal that seemed elevated by comparison to other Nova Scotia harbours, harbours of New Brunswick, New York Bight and Long Island Sound, and Gulf of Maine. No information was available in the literature for La, Se, Ti and Tl.

Sediment compositions of 5 Bras d'Or sites consisted, essentially, of superficial muds (<63μg) and negligible sand particles. Organic carbon is used to assess the role played by the organic fraction of sediments in the transport, deposition and retention of trace metals (Loring and Rantala, 1992). A weak trend between organic carbon and metal concentrations was observed in the present study. That is, sediments from Denys Basin containing the lowest metal concentrations had the lowest organic carbon (2.0%). Organic carbon values were intermediary in East Bay (3.4%) and Baddeck Bay (4.9%). The highest levels were in Nyanza Bay (6.2%) and Whycocomagh Bay (6.6%). Loring *et al.* (1996), by comparison, reported values for harbours around Nova Scotia: <1.0% organic carbon in the Annapolis Basin to 17.70% in organic-rich sediments (containing wood fibres), from a site near a pulp and paper mill at Liverpool, N.S.. Tay *et al.* (1991) reported a range of 0.77% organic carbon in Whidby sediments (Sydney, N.S.) to 20.3% in Sydney Tar Pond, N.S.; 3.8% to 8% in Halifax Harbour sediments, and 3.98% at a control site. Bras d'Or sediments contained a relatively small range of low organic carbon values, and were not organically-enriched compared to the above mentioned organic-rich sediments.

Organic carbon content relates to the potential metal-binding ability of the sediments. Several studies show that organic carbon does not indicate the bioavailability of metals, or the nature of the relationship between sediment metals and uptake in biota such as molluscs, *Macoma balthica*, exposed to Halifax Harbour sediments (Tay *et al.*, 1991); and amphipods (Landrum *et al.*, 1987; Swartz *et al.*, 1990; Di Toro *et al.*, 1990). Buckley and Hargrave (1989) suggested that organic-rich sediments from Halifax Harbour, N.S., were in a state of strong chemical reduction, and that high metal concentrations were probably present as highly insoluble metal sulfides. Furthur investigation, such as bioavailability studies, may contribute to the understanding of the lack of relationships observed between sediment metal and flounder metal levels in the Bras d'Or study.

4.2. RANKING FOR GEOGRAPHIC DISTRIBUTION OF METALS

The concentrations of 21 metals were determined in 3 sample types: winter flounder liver and kidney, and associated sediments, to establish baseline levels. In attempting to relate flounder contaminant levels with the associated environment, the liver and kidney have been ranked. There is essentially no difference between the site ranking of contaminants for liver and kidney. Scores for the liver are in the following order: East Bay (18.02), Whycocomagh Bay (14.68), Baddeck Bay (13.60), Denys Basin (10.91), and Nyanza Bay (10.22). Scores for kidney have a similar order: East Bay (16.63), Baddeck Bay (13.86), Whycocomagh Bay (13.62), Denys Basin (12.77), and Nyanza Bay (12.05). Although the ranks for Whycocomagh Bay and Baddeck Bay are reversed between the liver and kidney, the scores on which the ranks are based, do not differ significantly. The contaminant ranking for sediments is quite different from kidney and liver ranking. Scores for sediments are in the following order: Baddeck Bay (17.99), Nyanza Bay (17.87), Whycocomagh Bay (17.64), East Bay (15.80), and Denys Basin (8.51). There is no significant difference for the first four site rankings for sediments. However, Denys Basin has a significantly lower rank.

Other research has demonstrated that contaminants within an organism do not necessarily reflect levels in associated sediments. Greig and Wenzloff (1977) found that copper, manganese and zinc in winter flounder livers from cleaner sites in New York Bight and Long Island Sound, were twice as high as the levels found in fish from sites characterized by more elevated sediment contaminants. Also, data were similar for flounder collected at a sewage disposal area and those collected elsewhere, including offshore stations, and the authors concluded that sewage sludge had no demonstrable impact on Cu, Mn, and Zn concentrations in winter and yellowtail flounder. In another study of pollution at three sites in Long Island Sound, Gronlund *et al.* (1991) also found that the concentrations of trace metals in winter flounder liver varied considerably among sites and appeared unrelated to sediment concentrations. These findings agreed with other studies (Zdanowicz *et al.*, 1986; Varanasi *et al.*, 1988) where sediment trace metal concentrations and fish tissue levels were not correlated. Such differences may result from the fact that contaminant levels within an organism result from a complexity of factors including bioavailability, uptake from water, food, and sediments, metabolism, etc.

4.3. METAL CONCENTRATION TRENDS

4.3.1. WITH BIOLOGICAL PARAMETERS

Liver concentrations of Cd (weak trend), Co, Mo and Ni decrease as liver weight increases. Hardisty *et al.* (1974) reported both a seasonal and size (length) variation in the concentration of Zn in whole fish samples of the European flounder, *Platichthys flesus,* from intake screens of a nuclear power station at Oldbury-on-Severn, U.K. In particular, highest Zn levels were recorded for the smallest flounder in summer and autumn samples (reverse trend with length and age during these sampling periods); Zn concentrations were more elevated, overall, in February samples and remained constant despite size class, wit the exception of the largest flounder, in which Zn concentration was more elevated. In the same study, Cd and Pb tended to be highest in the longest and oldest flounder sampled.

In Bras d'Or flounder kidney, concentrations of Cu, Mo, and Ti vary inversely with kidney weight, and this may suggest a weight effect on these 3 metals. No information was available in the literature regarding such relationships in flounder kidney. Furthur research is required.

Certain elemental concentrations are known to exhibit size- and age-dependent effects within particular marine species, and independent of exposure to contaminants (Atlantic croaker) (Evans *et al.*, 1993). Decreased Cr and Ni concentrations have been observed in mussels of increasing size (Stronkhurst, 1992). In a review by Evans *et al.* (1993), metal uptake in relation to size may be affected by the following factors: differences in uptake, assimilation and excretion rates; changes in relative organ size and changes in lipid content composition with growth.

4.3.2. BETWEEN LIVER AND KIDNEY

In this study, liver concentrations were generally more elevated than kidney metals with the exceptions of beryllium, lithium, selenium, and strontium, which had slightly higher kidney levels. Li, Se, and Sr were higher at all 5 sites. Be was generally 1.0-1.5 times the liver concentration, but was 6 times the liver value in Nyanza Bay samples. Kidney Li was generally about 1.5 times the liver concentration. Kidney Se and Sr were slightly higher than liver concentrations, except in Baddeck Bay samples, in which kidney Sr levels were 2.54 times higher. There are no documented cases of elevated Be, Li, Se, and Sr in kidney compared to flounder liver. The biological roles of these elements in kidney requires further investigation.

Although generally, in Bras d'Or flounder, most metals have more elevated concentrations in liver, direct relationships between liver and kidney concentrations are evident for: Cd, Cu, Mo (except at Denys Basin), Pb, Se, Sr (except Baddeck Bay), Tl (except Denys Basin and Whycocomagh Bay), U, and V (except Whycocomagh Bay). Although certain metals have been analyzed in both kidney and liver of fish species, metal trends between these 2 organs have not been discussed (Wright, 1976; Windom *et al.*, 1973).

4.3.3. BETWEEN TISSUES AND SEDIMENTS

In this investigation, no obvious relationships between metal levels in the sediments and biota were observed except for Cd and Cu in flounder kidney and liver, and Mn in the kidney, all of which seem to reflect sediment levels. This suggests the possibility of using these 3 metals for monitoring discharge associated with contamination from anthropogenic sources. Hanson (1997) reported that contaminant levels (metals and organics) in the livers of winter flounder and Atlantic croaker were elevated in samples exposed to sites characterised by greater habitat contamination. Based on distance from a point source of pollution at the head of Hardangerfjord, Norway, Julshamn and Grahl-Nielsen (1996) reported that Hg in flounder liver tended to decrease with increasing distance from the pollution source, as did As in flounder muscle. No information for comparison between fish and sediment metals was available.

4.4. METAL INTERACTIONS

In the liver of Bras d'Or flounder, cadmium, cobalt, molybdenum, and nickel are related by a positive trend. A second group of metals, copper, manganese, selenium and silver, are related by a positive trend. It is known that one metal can influence the uptake, accumulation and toxicity of other metals, or pollutants in biota, including fish, and metal interactions have been reported for some marine species: Ag-Cu in lobster (*Homarus americanus*) (Chou *et al.*, 1981); Fe-Hg interactions in the bivalve (*Mercenaria mercenaria*) (Fowler *et al.*, 1975); Cd-Se interactions (Magos and Webb, 1980). In winter flounder, Hanson (1997) observed that depletion of hepatic Zn and Cd, was coincident with the accumulation of Hg and Ag.

The trends observed in Bras d'Or flounder may suggest interactions between Ag, Cu, Mn and Se in liver tissue, and between Cd, Co, Mo and Ni in liver tissue. Concentrations of the latter 4 metals are also inversely related to liver weight. Hence, such data must be interpreted with caution as observed trends may be attributed to either a size effect or metal interactions, or some combination of both.

In winter flounder kidney, manganese and arsenic are related by a positive trend, as are uranium and thallium. Manganese is a required element, but arsenic has no known biological role. Uranium and thallium are chemically related, and interactions, therefore are possible, as in lobster (Chou and Uthe, 1995).

5.0. SUMMARY/CONCLUSIONS

This paper reports the findings of an investigation of baseline levels of 21 metals in winter flounder and associated sediments from a relatively pristine marine environment, Bras d'Or Lake, Nova Scotia. Baseline contaminant data serve as an essential reference point for the effective monitoring of marine environmental quality. Some of the major findings are as follows:

1. Cd, Cu, and Mn were the only metals that had a good correspondence between kidney, liver, and sediments, and between kidney and sediments in the case of Mn, implying that these biological samples may reflect the geographic distribution of these 3 metals in the Bras d'Or Lakes.
2. Overall, 21 metals were ranked for mapping geographic distribution in Bras d'Or Lakes. Rankings are similar for metals in the liver and the kidney, but do not agree with the ranking for sediments. Based on ranking by flounder kidney and liver, East Bay has the most elevated score. By contrast, in the sediment ranking, Baddeck Bay has the most elevated score, and Denys Basin has the lowest. Such differences indicate that the assessment of contaminant distribution within the marine environment is a complex process.
3. Sediment metal concentrations were elevated in Ni at some sites in the Bras d'Or Lakes. The source of elevated Ni discharge is not known.
4. Sediment compositions consisting of superficial muds ($<63\mu g$) had a weak trend between organic carbon and metal concentrations. Sediments from Denys Basin containing the lowest

metal concentrations had the lowest organic carbon (2.0%); the highest levels were in Nyanza Bay (6.2%) and Whycocomagh Bay (6.6%).
5. The concentration of As in the livers of East Bay flounder was about 5 times higher than the concentration in Denys Basin flounder livers.
6. Positive relationship between concentrations of Cd, Cu, Mo, Pb, U, and V in the kidney and liver were observed in this study. Despite different storage capacities in these 2 organs, the uptake of these metals was proportionally assimilated by flounder.
7. Liver Cd, Co, Mo, and Ni showed interactions and were inversely related to liver weight. Implications of weight relationship and interactions requires furthur study.
8. Liver Ag, Cu, Mn, and Se showed interactions.
9. Kidney Cu, Mo, and Ti showed a reverse relationship with kidney weight. Interactions between Mn and As, and Tl and U were also observed.
10. Data for several of the elements presented in this study, particularly in the kidney, were not reported elsewhere in the literature.
11. Kidney Be, Li, Se, and Sr were generally higher than liver at 5 sites in the Bras d'Or Lakes.

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