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BIOGEOCHEMICAL STUDIES OF WINTERING WATERFOWL
IN THE IMPERIAL AND SACRAMENTO VALLEYS

J. J. Koranda
M. Stuart
S. Thompson
C. Conrado

October 1979

Lawrence
Livermore
Laboratory

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IN THE IMPERIAL AND SACRAMENTO VALLEYS

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OCTOBER 1979

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ABSTRACT *

Trace and major elemental composition were determined in the organs of wintering waterfowl in the Imperial and Sacramento Valleys of California, and in soils, sediments, and agricultural fertilizer that constitute the various sources of elements in the waterfowl. These data provide a biogeochemical baseline for waterfowl populations wintering in an area being developed for geothermal power.

This baseline in the Imperial Valley is affected by soil and sediment composition, agricultural effluents in irrigation and stream water, and spent shot deposited by hunters in waterfowl habitats. The waterfowl acquire a set of trace elements from these sources and concentrations increase in their organs over the wintering period. Nickel, arsenic, selenium, bromine, and lead are the primary elements acquired from soil sources, agricultural effluents, and spent shot in the Imperial Valley. The assessment of effects from geothermal effluents on waterfowl populations is complex because there are large influxes of materials into the Imperial Valley ecosystem that contain trace elements, i.e., irrigation water, phosphatic fertilizers, pesticides, and lead shot. Multiple sources exist for many elements prominent in the expected geothermal effluents.

The relationships between the two California valleys, the Imperial and Sacramento, are apparent in the trace element concentrations in the organs of waterfowl obtained in those two valleys. Arsenic is absent in the waterfowl organs obtained in the Sacramento Valley and relatively common in the Imperial Valley waterfowl.

The effect of any release of geothermal effluent in the Imperial Valley waterfowl habitats will be difficult to describe because of the complexity

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of the biogeochemical baseline and the multiple sources of trace and major elements in the ecosystem. In addition, mortality in waterfowl populations in the Imperial Valley may result from a variety of climatological, epidemiological, and lead toxicity factors that should be investigated in the event of any large scale epizootic event.

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Fig. 1 - Wintering snowgeese in the Imperial Valley.

INTRODUCTION

BACKGROUND

The trace element composition of wild animal populations has excited the interest of ecologists and game biologists for over 50 years because of increasing levels of contamination in the biosphere. Undoubtedly the increase in the magnitude of effluents, greater sensitivity in methods of detection, and an enhanced awareness of these environmental problems have contributed to the development of concern over trace element contamination.

One of the first reports of trace element contamination in migratory waterfowl was in 1919 by Wetmore¹ and the number of similar reports has increased each year. Migratory waterfowl in the Americas may be exposed to trace element contamination of various kinds as they biannually pass through areas of technological development in the continental United States, Canada, and Alaska and return to wintering grounds in the southern United States, Mexico, and Central and South America. Their biannual passage through these regions brings them into contact with effluents from power plants, industrial manufacturing, and urban activities. Large populations of waterfowl are thus exposed to many kinds of trace element and organic materials that enter surface hydrologic systems. Agricultural activity also contributes significantly to the loading of surface water with trace elements from phosphatic fertilizers, defoliants, and pesticides.

North American waterfowl constitute the largest population of wild game animals used by man that regularly comes into contact with technological and agricultural effluents.² They frequent estuarine, riparian, and lacustrine habitats into which many kinds of effluent are discharged and

where trace elements are concentrated by hydrologic patterns. Other large populations of game animals, such as deer and upland birds, typically come into contact with this variety and intensity of effluents only on a local scale. Waterfowl eat large quantities of emergent and submerged vegetation, planktonic plants and animals, and various small invertebrates. Many species of waterfowl "browse" or "graze" in agricultural fields, gleaning the residual grain left from harvesting. Many of the food organisms take up and, in many cases, concentrate trace elements from the environment so that the potential for food chain or trophic concentration effects is large in waterfowl ecosystems.^{3,4}

Waterfowl, and most gallinaceous birds, must take in fine mineral particles, generally called "grit", to aid in the comminution and subsequent digestion of seeds and other hard food materials. This requirement may closely couple the birds' physiology and trace element composition to the characteristics of the local substratum, and to any other materials passively ingested with the grit.⁵ Spent lead shot ingested with grit and sediments accounts for most of the lead observed in the present populations of waterfowl we sampled. However, the enormous quantities of lead released to the environment each day from automobiles far outweigh that from other technological sources. This automotive lead is generally deposited within a few hundred meters of heavily-traveled roads⁶ and may be suspect if bodies of water where waterfowl abound are adjacent to those roads. There is some evidence that a fraction of this automotive lead is more mobile and may be transported into environments distant and down-wind from large urban areas with their large populations of people and automobiles.^{7,8} Biologists should be aware of this transport phenomenon when conducting studies of lead behavior in the environment.

Materials in the proventriculus, gizzard, and intestinal tract of the waterfowl are dissolved and subsequently pass across the gut wall. Thus typically, food materials, major and trace elements from the substratum, and any contaminants reach the circulatory system and are then either excreted or deposited in target organs.⁹

The migratory waterfowl, therefore, has two primary sources of its trace element burdens:

1. Organic matter - food organisms containing organically-bound elements, and
2. Inorganic matter - grit or sediments, and soil ingested with food materials, containing elements associated with the geochemistry of the region, and contaminants.

Aquatic plants are known to concentrate trace elements many times over in the amount in either the water column or the sediments in which the plant grows. Because of precipitation, flocculation, and other physio-chemical processes that typically occur in estuarine and lacustrine habitats, sediments are also often enriched in elements when compared to the water column above them.

SCOPE

The data obtained in the present study were part of an environmental baseline program concerned with the effects of a developing geothermal resource in the Imperial Valley of California.¹⁰ The Salton Sea National Wildlife Refuge, located at the northern end of the Imperial Valley and along the southern shore of the Salton Sea, is one of the major wintering areas in California for many species of migratory waterfowl and aquatic

birds. Some species will migrate further to Mexico and Central and South America; others will remain in the Imperial Valley and other California areas for the entire winter period. The distribution of waterfowl on both the breeding and winter ranges and the migratory routes typically used are given in the book by Bellrose.¹¹

The primary goal of our studies was to detect and quantitate trace elements in waterfowl populations that winter in Imperial Valley near the geothermal development sites before geothermal power stations became operational. The Salton Sea National Wildlife Refuge and other waterfowl habitats are within two miles of geothermal well sites and power plants are being constructed now. These data will constitute part of baseline information on the region that may be related to post-operational conditions if the need arises later, and they may be used to characterize the status of western populations of migratory waterfowl as increasing or decreasing levels of trace element contamination occur.

Often acquiring this type of information raises many basic physiological and ecological questions important for interpreting the data. Foremost of these questions is, what are the time-relationships involved in an animal's acquiring a unique and locally-derived set of trace elements, or how long does it take for a waterfowl to equilibrate with a new spectrum of trace elements (and other contaminants) when it enters a new ecosystem, i.e., the wintering or breeding ranges? Waterfowl depend entirely upon regionally produced foods, either natural or agricultural, except when they are fed grain that may originate elsewhere.

The basic constituents of tissues and organs, i.e., carbon, oxygen, and hydrogen, are known to turn over at slow rates relative to the general

metabolism of the animal and the tissue. However, trace elements, which are often bound to macro-molecules in tissues, and involved in enzymatic reactions, will have varying residence times in the waterfowl and its organs.

The basic premise that trace element composition of a free-ranging population of waterfowl has some relationship to the geochemistry of the population's range was demonstrated by Hanson and Evans¹². However, the influence of different areas of the total geographic range, especially the distinct breeding and wintering ranges of waterfowl, on trace element composition requires further elucidation.

Superimposed on the release and environmental transport of trace element contamination from any source will be the influence of local parent materials and soils, and the effects of regional agricultural practice. Both of these influences may "label" a given ecosystem with endemic trace elements that can have considerable biological and physiological significance.

METHODS

BIRD SAMPLING

We obtained most of the samples in this study from birds killed by hunters at authorized hunting sites controlled by the State of California. We also received illegally killed game and non-game birds, confiscated by game management officials. The Wister Wildlife Unit of the State of California adjacent to the Salton Sea National Wildlife Refuge was the collection site for most of the Imperial Valley animals. The Sacramento National Wildlife Refuge near Willows, California was the site for the Sacramento Valley collections, which were also made at game checking

stations. Waterfowl are hunted from October to January at both locations and spend an additional one to two months after the hunting season there before departing for the northern breeding range.

Organ Sampling

To avoid metal contamination, a synthetic ruby knife made from a defective laser rod was used to open the visceral cavity and to excise the organs from freshly-killed waterfowl brought to the checking station. The organs were immediately frozen on dry ice. Birds that had the visceral cavity opened by gunshot were not sampled; only birds with intact bodies were chosen. Usually the liver and kidneys were taken from the carcass, but in an early series the heart, lungs, and brain were also collected. Wings, including feathers and bone, were collected from a series of animals and will be analyzed later to compare with the internal organ concentrations. Feathers were analyzed by Hanson and Evans¹² and others^{8,11} for trace constituents after carefully removing surface contamination. In addition, wing bones are often analyzed by investigators for lead.

The frozen organs were freeze-dried in the laboratory in separate vials on a large vacuum manifold and then ground to a powder in a SPEX mill using lucite pellets. The ground organs were re-dried either in the freeze-drying system or in a vacuum oven at a low temperature (50°C) for several days to remove any residual water.

TRACE ELEMENT ANALYSES

The dried and ground samples were then pressed into a 22 x 2 mm disk that typically weighed between 250 to 300 mg and were then analyzed for trace elements by non-dispersive x-ray fluorescence spectroscopy using

either an x-ray or isotopic source. Excitation x-ray emissions were analyzed with a silicon detector at liquid nitrogen temperature and a 1024 channel pulse height analyzer.¹⁵ Some samples will not form a dimensionally stable disk and a binding agent such as Avicel or stearic acid is used. These additives are spectrochemically clean and at a concentration of 20 to 50% will effectively bind the sample. The x-ray fluorescence spectra were analyzed with a computer program that provides the concentration of the element in micrograms per gram dry weight (ppm) and the associated analytical error. With these methods the sample does not reach the high temperatures that may cause the loss of elements such as arsenic. Acids, which often contain metal contaminants, are not used in these analyses.

RESULTS

Our results can be divided into five sections:

- Analyses of trace elements in organs from various bird species collected in the Imperial and Sacramento Valleys.
- Calculations of mean and median values based on the above analyses
- Analyses of trace elements in the wintering habitats of the waterfowl
- Comparison of trace element concentrations in organs of birds from various locations
- Statistical summaries

Tables 1 and 3 through 9 contain data on the concentrations of trace elements in the livers of waterfowl, aquatic, and land birds collected in

the Imperial Valley. Data from similar studies on birds in the Sacramento Valley are shown in Table 10.

Kidneys were analyzed and trace element data from Imperial Valley and Sacramento Valley waterfowl are tabulated in Tables 11 through 18, and 19 and 20, respectively. Muscle, heart, lung, and brain tissue were analyzed also and these data are shown in Tables 21 through 26.

Calculations of mean and median concentrations and frequency of occurrence of elements in the birds are listed in Tables 27 through 30, and Tables 32 and 33. Comparisons between trace elements in various bird species collected in the Imperial Valley with those collected in the Sacramento Valley are in Table 31.

To correlate the trace elements in birds with those in their physical environment, analyses were made of soil from the two valleys. The results are shown in Tables 34 and 36.

TRACE ELEMENT ANALYSES OF ORGANS

LIVER

In Table 1, the concentration of each trace element in the livers of pintail ducks from the Imperial Valley are shown. The prominent and usual occurrence of metals in the liver is demonstrated by the low levels of nickel and manganese, intermediate levels of copper and zinc, and high concentrations of iron. All of these metals may be considered normal constituents of the liver of wild animals. For comparison, typical concentrations of trace elements in mammalian organs ¹⁶ are shown in Table 2. Notable in our series on the liver analyses of pintail ducks is

Table 1. Trace element concentrations in livers of pintail ducks (*Anas acuta*) collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As ^a	Se	Br	Rb	Sr ^b	Pb ^a
23 Oct. 1975	VKD-004	10080	132.4	16.8	2554	1.2	138.4	141.7		7.9	20.9	8.2		
	VKD-007	9935	156.5	19.2	3508	1.3	74.5	117.5		7.3	13.8	13.8		
	VKD-009	11170	98.8	17.5	2918	1.3	135.4	163.0		3.6	7.8	6.8		
	VKD-010	11910	173.9	19.4	3880	1.7	160.0	203.0		8.0	4.3	5.3		9.2
	VKD-012	11290	201.0	23.8	4636	1.9	30.0	213.0	1.3	6.3	3.7	4.4		
	VKD-015	10390	132.2	22.6	2258	1.2	237.9	212.4		12.9	2.4	2.6		
	VKD-022	9604	122.0	12.5	1315	0.7	60.5	119.2		11.5	3.2	8.0		
	VKD-027	9261	139.4	14.5	2485	0.9	41.6	223.3	2.2	19.9	6.8	8.6		
	VKD-028	6604	122.5	14.7	1766	0.8	72.6	223.0		5.7	6.7	7.1		4.5
	VKD-030	9772	209.5	16.3	3418	1.4	142.4	138.1		9.6	8.2	8.8		
1-2 November 1975	VKD-042	10620	80.8	8.0	702	0.6	122.6	56.3		6.1	7.2	4.5		
	VKD-044	11060	198.3	15.9	2857	1.0	71.6	117.1		13.3	14.0	4.9		
	VKD-045	8007	ND ^c	11.9	3521	ND	171.2	172.2		9.0	11.1	5.5		
	VKD-046	10260	171.0	18.2	2903	1.3	189.1	186.1		5.7	20.4	4.4		
	VKD-047	8657	134.3	16.3	3066	1.4	47.6	89.8		4.1	8.8	7.1		
	VKD-048	10500	187.2	11.7	2905	1.4	61.9	100.2		6.0	11.0	6.4		
	VKD-049	8363	59.1	16.7	1688	0.7	62.8	94.0		3.7	3.0	7.3		
	VKD-050	10010	100.1	16.1	2071	0.8	76.8	110.7		4.9	2.4	9.9		
	VKD-051	8922	100.4	12.2	1290	0.5	96.0	104.5		7.6	12.1	9.4		
	VKD-053	9913	77.1	11.9	1929	0.9	131.4	123.4		13.3	7.3	18.5		
17 January 1976	VKD-057	8863	255.2	13.7	3064	1.0	79.9	230.3		11.5	18.3	1.8		
	VKD-066	10020	65.4	12.1	3301	1.3	144.9	158.4		8.4	5.5	4.8		
	VKD-067	12300	162.1	16.8	1874	0.7	137.5	236.7		4.8	6.5	17.9		
	VKD-078	11990	140.2	22.2	4575	2.0	237.6	174.0		12.4	11.5	4.2		
	VKD-084	9963	141.8	18.6	2972	1.3	127.2	136.6		9.6	12.3	6.8		
	VKD-086	10530	200.6	18.9	3822	1.5	60.2	131.9		23.1	24.9	2.6		1.1
	VKD-090	9732	84.0	22.0	1976	0.8	62.7	132.8		32.9	10.0	3.1		
	VKD-093	8572	298.8	18.3	5305	2.1	32.4	290.7	1.0	23.6	7.2	3.3		
	VKD-094	11030	78.6	18.5	2709	1.0	108.5	142.6		6.9	13.5	3.6		
	VKD-102	11730	24.9	23.5	3502	1.6	108.6	139.1	2.3	20.6	5.8	10.6		133.3
	VKD-106	10720	629.6	21.8	2023	1.1	141.8	202.6		15.6	5.2	2.9	2.0	
	VKD-108	10750	329.9	18.3	2480	1.1	79.8	99.4		5.5	4.4	3.7		
	VKD-114	10560	164.9	14.8	3043	1.3	612.5	117.4	1.0	15.0	6.1	2.2		
	VKD-118	9757	178.5	15.3	5321	2.1	114.1	123.0		23.8	6.3	1.9		
	VKD-119	9858	137.4	16.1	4364	1.9	169.8	159.0		6.3	6.6	6.1		1.0
	VKD-124	11800	175.6	18.4	4256	1.7	61.3	154.5		16.9	8.0	2.6		2.0

^a Detected only in specimens collected on 23 October 1975 and 17 January 1976^b Detected only in specimen VKD-106

Table 2. Elemental Composition of Mammalian Organs^a

	ug/g dry wt (ppm)				
	Brain	Heart	Kidney	Liver	Muscle
Al	0.9	0.8	1.1	1.7	0.7
As	0.08	0.01	0.34	0.5	0.16
B	0.6	0.2	0.2	0.48	0.31
Br ^b	3.0	8.0	16.0	10.0	4.0
Ca	320.0	150.0	390.0	140.0	105.0
Cd	3.0	0.05	130.0	6.7	0.06
Cr	0.12	0.02	0.05	0.02	0.04
Cu	22.0	14.0	12.0	19.0	3.1
F	2.0	2.0	3.2	4.0	5.0
Fe	200.0	190.0	290.0	520.0	140.0
K	11600.0	9200.0	7800.0	7400.0	10500.0
Mg	550.0	640.0	550.0	480.0	630.0
Mn	1.1	0.8	3.8	3.7	0.2
N	99000.0	132000.0	115000.0	112000.0	108000.0
Ni	0.3	0.2	0.2	0.2	0.008
P	12200.0	6000.0	6900.0	7400.0	6300.0
Pb	0.24	0.2	4.5	4.8	0.2
Rb	15.0	13.0	17.0	30.0	24.0
Se	2.1	0.7	2.1	2.1	2.5
Sr	0.08	0.1	0.24	0.06	0.05
U	---	0.03	0.03	0.04	0.03
V	0.03	0.04	0.05	0.04	0.04
Zn	46.0	110.0	210.0	130.0	180.0

^aAdapted from Bowen⁽¹⁶⁾^bLung - 16.0 ppm

the occasional occurrence of arsenic, lead, and strontium. Selenium, bromine, and rubidium are in all of the liver samples; however, of these three only selenium is required and in very low trace amounts.

The presence of arsenic and bromine in waterfowl is related to the presence of these elements in pesticides and defoliants used in the Imperial Valley agriculture. Although arsenical compounds appear to be decreasing in agricultural use, compounds such as cacodylic acid (dimethyl arsenic acid) are still used in the valley. Strontium is relatively abundant in the soils of the Imperial Valley, usually at 400 to 500 ppm. The usual source of lead in waterfowl is spent lead shot deposited in this habitat during current and past hunting seasons. In areas where there is heavy automobile traffic, contamination levels of lead may range from a few parts per million to over 2000 ppm in roadside habitats.

Sample VKD-102 had the highest concentration of lead and arsenic, and strontium was found only in the sample with the highest calcium concentration (VKD-106) in this series. Also maximum nickel and iron concentrations occurred in the same sample (VKD-118). The highest concentrations of trace elements except for potassium (VKD-067) and rubidium (VKD-053) were determined in the mid-January 1976 samples, after the general population of wintering waterfowl had been in the Salton Sea area for several months. Nickel is occasionally detected in the surface 15cm of the soils in the northern Imperial Valley and its only known source in the area is the triple phosphate fertilizers used at rates up to 300 lb per acre.

The same patterns of metal concentrations are present in the livers of the shoveler duck (Table 3), which is primarily a surface-feeder subsisting mainly on emergent vegetation and invertebrates. Low concentrations of nickel and manganese, intermediate concentrations of copper and zinc, and

Table 3. Trace element concentrations in livers from shoveler ducks (*Anas clypeata*) collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr ^b	Pb ^c
23 October 1975	VKD-011	11580	220.6	23.2	5959	2.3	159.9	164.3	0.8	14.6	31.5	8.6		
	VKD-014	10158	109.9	20.9	3923	1.5	72.4	152.8	ND ^a	19.2	12.9	10.0		
	VKD-023	10258	145.9	26.2	7186	2.6	65.2	121.0	0.8	20.5	24.0	5.8		
1-2 November 1975	VKD-031	10820	176.0	13.4	1778	0.9	70.5	123.4	ND	13.5	45.2	7.9		
	VKD-065	11538	184.5	14.3	2247	1.1	109.8	203.1	ND	9.2	42.7	3.6		
17 January 1976	VKD-073	13410	345.4	20.1	5604	2.3	12.5	136.9	1.4	12.3	7.4	20.7	0.8	
	VKD-077	15024	205.4	26.1	9937	3.5	57.4	275.4	ND	11.8	6.0	0.8		
	VKD-085	11573	171.6	21.8	7040	2.3	88.7	129.3	ND	23.2	33.1	6.8		
	VKD-088	11661	126.6	26.1	10760	4.1	34.5	143.8	3.4	24.9	20.2	18.8		
	VKD-091	10865	232.9	18.7	7817	2.9	15.5	143.9	1.3	19.7	9.0	15.0		
	VKD-098	12698	230.5	15.6	5085	2.0	17.9	184.2	1.5	10.3	47.0	7.9		
	VKD-111	11844	213.7	16.4	6752	2.7	27.6	115.3	ND	10.8	6.9	10.8		1.9
	VKD-112	11178	166.2	13.6	4120	1.9	14.3	111.6	1.3	14.1	8.9	20.9		
	VKD-115	13543	155.6	21.9	7014	2.5	62.3	177.9	ND	19.5	13.3	13.2		5.9
	VKD-116	14384	195.2	21.0	11494	4.3	12.8	117.4	2.0	10.1	6.3	24.6		

^a Not detected

^b Detected only in specimen VKD-073

^c Detected only in specimen VKD-111 and VKD-115

high concentrations of iron were also found in their livers. There is a high frequency of arsenic and only low levels of lead in the shoveler duck liver; this may be related to the feeding behavior of this species and a low exposure to lead shot. We note again that maximum iron and nickel were found in the same animal, and strontium was found only in that animal with the highest calcium concentration.

In Table 4 the trace element concentrations in the livers of the ruddy duck are seen. This species is the only diving duck in the main series of waterfowl sampled and subsists mainly on aquatic vegetation and invertebrates. The ruddy duck often has a relatively high intake of animal foods. The metals, nickel, manganese, copper, zinc, and iron are again prominent and iron and nickel maxima are correlated. Calcium, zinc, and lead maxima occur in the same sample. The maximum amount of lead in this species is higher than that usually assumed to be lethal to waterfowl.¹⁸

The trace element concentrations in the livers of green-winged teals are in Table 5. The mid-January 1976 samples distinctly show a higher nickel concentration than was found in ducks collected in October and November 1975. Strontium was detected in 41% of the samples of this species and arsenic in 12%. The maximum concentration of strontium again occurred in the animal with maximum calcium (VKD-097). The lead concentration observed in VKD-038 (40.2 ppm) is in the range of toxic effects. None of the essential elements appear in unusual concentrations in this animal (VKD-038); however, the calcium value is somewhat higher than the species mean concentration (296.1 vs 169.0 ppm). The bromine and selenium concentrations (296.1 vs 169.0 ppm) in the green-wing teal livers obtained in mid-January 1976 are higher than in the earlier 1975 series. Mean

Table 4. Trace element concentrations in livers from ruddy ducks (*Oxyura jamaicensis rubida*) collected in the Imperial Valley.

ug/g dry weight (ppm)													
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As ^a	Se	Br	Rb	Pb ^b
20-24 October	VKD-005	11605	86.0	24.5	3283	1.3	65.6	144.3		37.9	7.2	2.6	
1975	VKD-020	10817	117.9	13.2	1964	0.9	229.9	91.3		36.2	5.2	5.1	
	VKD-021	10750	126.0	16.2	2470	0.9	171.7	156.7		11.3	4.7	4.0	
1-2 November	VKD-036	11719	129.5	28.5	1803	0.8	111.4	120.6		13.6	8.7	2.4	
1975	VKD-064	11582	129.8	20.1	1462	0.9	119.7	132.0		44.8	4.8	3.7	
	VKD-069	13309	139.6	20.6	1821	1.1	365.0	159.3		77.1	4.2	3.9	
18 January	VKD-120	13911	167.3	16.9	2555	1.2	55.3	121.6		45.4	4.5	1.9	20.7
1976	VKD-121	9031	248.1	22.8	6153	2.4	89.1	166.8	1.4	46.5	5.8	5.8	97.8
	VKD-123	13839	111.6	20.7	1923	0.9	58.9	122.5		37.8	2.9	3.9	
	VKD-123	11981	83.9	17.7	609	0.05	123.6	130.8		143.9	2.3	3.4	

^a Detected only in specimen VKD-122

^b Detected only in specimen VKD-120 and VKD-121

Table 5. Trace element concentrations in livers from the green-winged teal (*Anas crecca*) collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As ^b	Se	Br	Rb	Sr ^c	Pb ^d
23 October 1975	VKD-001	6630	189.5	ND ^a	1094	ND	53.8	82.9		6.9	4.8	3.1	0.8	1.5
	VKD-003	8857	57.0	10.0	801	0.6	48.3	69.3		5.3	3.7	7.0		
	VKD-006	5725	67.4	12.8	1180	0.7	40.9	68.7		7.2	15.4	4.7		
	VKD-013	7679	88.7	12.9	1622	0.7	40.9	68.7		7.2	15.4	4.7		
	VKD-018	13690	84.4	20.4	2603	1.1	71.9	187.3		12.0	23.5	10.5		
	VKD-019	10840	103.9	14.6	1933	1.0	110.3	95.6		14.0	7.7	5.8		
	VKD-024	8432	44.7	16.2	1365	0.7	46.9	103.3		8.7	5.7	2.4		
	VKD-026	11230	126.5	15.3	2418	1.1	200.6	140.9		8.8	8.3	6.4		
1 November 1975	VKD-032	11230	129.6	21.2	3890	1.6	85.6	146.9		19.8	8.5	3.8		
	VKD-033	9635	138.0	17.3	4156	1.5	129.9	119.5		11.3	6.7	3.1		
	VKD-034	8570	99.0	17.4	3045	1.2	116.1	138.3		19.1	9.9	2.1		
	VKD-035	8716	178.7	ND	3271	ND	119.1	137.6		11.6	6.3	6.1	0.5	0.7
	VKD-037	9539	66.9	15.0	1600	0.6	86.4	99.9		10.8	9.2	3.5		
17 January 1976	VKD-038	9340	296.1	ND	2595	ND	91.2	133.1		11.2	5.2	4.2	0.4	40.2
	VKD-043	9595	144.3	ND	1474	ND	70.9	113.7		17.9	13.2	8.2	0.5	1.5
	VKD-052	7519	167.5	ND	3295	ND	48.9	76.6		10.9	4.6	3.4	0.5	
	VKD-054	8424	176.5	ND	1165	ND	106.8	135.7		14.5	10.9	2.7	0.6	0.9
	VKD-055	8819	169.9	ND	1776	ND	255.5	130.7	12.6	8.0	3.3	0.7	1.3	
	VKD-056	9200	210.1	ND	1517	ND	94.0	230.0		10.3	11.4	9.7	0.6	
	VKD-058	10010	269.8	6.7	7787	ND	135.4	141.8		18.0	12.9	3.7	0.7	2.5
	VKD-059	9544	159.7	ND	1356	ND	27.3	112.3		15.8	7.0	9.3	0.7	1.2
	VKD-060	8670	174.0	ND	1276	ND	63.4	118.0		16.0	14.1	6.7	0.7	1.0
	VKD-062	7895	126.4	ND	2743	ND	110.8	111.6		8.0	7.8	5.5		
	VKD-063	9326	138.6	ND	2283	ND	104.1	119.2		20.5	6.9	4.4	0.4	1.2
	VKD-081	9760	425.4	21.1	3162	1.3	78.6	124.3	1.1	23.7	21.2	3.1	1.0	8.2
	VKD-082	5437	114.6	17.1	2360	1.0	165.3	157.7		25.5	17.2	2.8		
	VKD-087	12130	152.1	15.5	4032	1.6	179.1	143.9	1.5	38.9	19.9	2.8		
	VKD-089	8503	330.0	21.5	3205	1.6	80.6	133.0		33.3	62.0	3.6		
	VKD-092	8668	112.7	11.6	2124	1.0	52.0	97.3		11.5	23.2	6.5		
	VKD-095	11400	286.0	14.2	2517	1.1	13.3	148.4	1.2	11.2	18.8	10.8		
	VKD-096	9605	123.5	16.6	1676	0.7	21.1	179.8	1.0	18.8	21.6	14.2		
	VKD-097	9664	529.9	16.2	1988	1.1	53.2	133.4		11.7	24.9	3.3	2.5	4.2
	VKD-101	12360	ND	22.8	3559	1.4	143.6	152.1		20.5	34.8	5.2		
	VKD-110	8786	12.4	15.9	2584	1.1	34.4	90.6		9.1	16.3	4.5		

^a Not detected^b Detected only in some 17 January 1976 specimens^c Detected only in 1 November 1975 and 17 January 1976 specimens^d Detected only in VKD-001, VKD-035, and in 17 January 1976 specimens

selenium concentrations for October and November 1975 are 12.4 ppm, while the mean concentration for mid-January 1976 is 21.2 ppm. The early vs late bromine concentrations are 8.9 and 26.0 ppm, respectively. Numerous brominated pesticides are used in agriculture in the Imperial Valley and would be an obvious source for this non-essential element to wintering waterfowl. The selenium is most likely derived from soil or sediments.

In Table 6 are listed the results of analyzing the livers of snowgeese collected in the Imperial Valley. All animals collected had nickel and selenium, and maximum concentrations of iron, nickel, selenium, bromine, and rubidium occurred in the same animal (VKG-099). All of these samples were obtained on 17-18 January 1976 and therefore reflect equilibration with Imperial Valley trace element sources over most of the wintering period.

Trace element concentrations in livers from miscellaneous species of waterfowl collected in the Imperial Valley are shown in Table 7. Several species of diving ducks (canvasback, baldpate, bufflehead, redhead, and goldeneye) are represented in this series of samples. Nickel was not detected in any of these birds and arsenic occurred in only two ducks (VKD-070 and VKD-072) collected on 17 January 1976. Lead occurred primarily in diving species and also in the cinnamon teal. Maximum calcium and strontium concentrations occur in the same duck (VKD-125). Bromine concentrations are somewhat higher than expected from the soil sources and are elevated in several ducks (VKD-002, VKD-070, and VKD-125). Many of the waterfowl obtained in this study have elevated bromine concentrations which are undoubtedly related to the use of brominated pesticides in the area's agriculture. Analysis of organs with high bromine concentrations for pesticides are being made to determine the source of bromine. The use of DBCP (di-bromo-chloro-propane) in the Imperial Valley at the time of this

Table 6. Trace element concentrations in livers from snow geese (*Chen caerulescens*) collected in the Imperial Valley.

ug/g dry weight (ppm)												
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb	Pb ^b
17-18 January	VKG-071	14440	158.1	11.9	2134	1.1	61.4	123.9	5.1	3.2	1.0	
1976	VKG-075	9186	146.5	8.0	2861	1.5	51.5	126.6	4.2	2.8	ND ^a	
	VKG-076	6865	111.7	7.6	2632	0.9	29.1	92.1	4.2	2.9	1.4	
	VKG-080	8324	163.8	9.7	2021	0.9	96.6	95.9	3.9	2.4	1.1	
	VKG-083	10040	51.1	9.9	1840	1.0	44.8	85.1	2.6	2.1	2.1	
	VKG-099	11280	164.6	12.9	5398	2.1	16.3	103.4	11.0	12.1	10.3	
	VKG-103	11030	148.6	11.8	2551	1.0	59.6	133.0	6.8	3.7	2.9	
	VKG-104	8966	59.4	6.7	614	0.7	19.3	74.0	2.3	2.5	1.6	
	VKG-105	12470	156.6	8.7	1794	0.7	101.3	163.0	4.8	3.6	1.9	
	VKG-107	9784	92.1	17.0	2540	1.2	82.4	151.7	6.2	3.4	2.4	
	VKG-109	11640	61.5	11.5	1948	1.1	85.5	129.6	4.9	2.0	1.9	4.4
	VKG-113	8672	120.6	7.2	1640	0.7	53.0	114.6	4.7	2.9	1.7	
	VKG-117	10820	129.1	6.6	2114	0.7	93.2	195.5	5.0	2.8	1.7	
	VKG-126	14120	247.5	9.7	2151	1.0	89.2	182.5	6.9	3.8	2.6	
	VKG-127	13940	212.0	13.5	3174	1.5	67.6	149.5	4.5	2.4	0.9	
	VKG-128	11250	196.0	8.3	1533	0.8	92.1	125.0	4.2	4.5	1.1	
	VKG-129	11020	139.9	9.3	2154	1.0	65.9	113.8	5.5	4.0	1.8	
	VKG-130	13610	432.6	15.1	3862	1.8	60.8	129.6	4.9	3.6	ND	

^a Not detected

^b Detected in only specimen VKG-109

Table 7. Trace element concentrations in livers from miscellaneous species of waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Species	Specimen	K	Ca	Mn	Fe	Cu	Zn	As	Se	Br	Rb	Sr	Pb
23-24 October 1975	Canvasback	VKD-002	10100	121.0	5.1	1990	75.1	222.0	ND ^a	4.0	28.5	5.8	0.6	ND
	Widgeon	VKD-008	8390	129.0	ND	1870	171.0	187.0	ND	7.5	5.1	2.9	0.5	ND
	Widgeon	VKD-025	8470	142.0	ND	3010	132.0	194.0	ND	4.6	3.8	5.2	0.8	ND
	Baldpate	VKD-017	10300	151.0	ND	3700	141.0	162.0	ND	17.5	4.9	4.1	0.8	0.7
	Bufflehead	VKD-029	10100	95.7	10.1	3230	25.8	105.0	ND	19.5	12.1	6.4	0.6	0.7
1-2 November 1975	Bufflehead	VKD-068	10600	210.0	4.2	494	25.5	98.1	ND	8.5	13.2	47.3	1.1	2.1
	Redhead	VKD-040	9664	125.0	9.4	3390	121.0	293.0	ND	5.5	9.3	3.3	0.8	1.1
	Mallard	VKD-041	8320	229.0	ND	4490	52.8	114.0	ND	8.5	13.2	7.5	1.5	ND
	Can. Goose	VKG-039	10810	180.2	ND	1759	73.4	213.1	ND	4.5	7.5	7.9	0.4	ND
	Can. Goose	VKG-061	8192	151.9	ND	1585	81.0	174.6	ND	3.8	6.9	5.6	ND	ND
17 January 1976	Redhead	VKD-070	7430	252.0	ND	4380	37.1	232.0	0.3	3.8	21.2	6.5	1.1	0.8
	Goldeneye	VKD-072	10200	130.0	ND	3350	13.7	173.0	0.3	7.9	4.5	12.6	0.3	ND
	Cinn. Teal ^b	VKD-074	8160	133.0	4.9	2940	125.0	138.0	ND	10.2	14.0	13.5	0.6	1.4
	Cinn. Teal	VKD-125	10200	838.0	ND	498	20.8	90.7	ND	7.3	29.1	9.9	5.6	5.0
15 February 1976	Can. Goose	VKG-146	8473	239.6	ND	904	11.4	95.8	ND	4.3	4.5	1.8	ND	ND
	Can. Goose	VKG-173	9763	230.3	9.6	942	24.8	113.1	ND	3.0	2.7	ND	ND	ND
	Can. Goose	VKG-174	10770	205.0	9.8	496	20.7	106.8	ND	2.8	2.1	ND	ND	ND

^a Not detected

^b Cinnamon Teal

study would be a strong local source of this persistent brominated compound which is not broken down in the body and would be detectable in the organs analyzed in this study.

Trace element concentrations in the livers of Canada geese, cattle egrets, a great blue heron, and a brown pelican are listed in Table 8. No nickel, arsenic, or manganese were detected in the six gulls analyzed, but the entire group had strontium in the liver. This is probably related to the gulls' habit of feeding in agricultural regions in freshly plowed fields, often concurrently with the plowing operation. The ingestion of surface soil and organisms living in the soil is an obvious source of strontium prominent in this species.

A great blue heron and a brown pelican were obtained in an opportunistic collection made by the Salton Sea Wildlife Refuge personnel and represent two other aquatic life histories somewhat related to the waterfowl. The data cannot be discussed in depth because of the single values. The great blue heron feeds in drainage ditches, which may be more closely related to the agricultural irrigation water environment, and contained both nickel and arsenic in its liver.

The liver data on three species of land birds obtained for comparative purposes can be seen in Table 9. The roadrunner, a roadside scavenger, had the spectrum of trace elements usually observed in many waterfowl species, with arsenic found in one specimen. Three pheasants were collected and were similar to waterfowl in some aspects, i.e., strontium was detected only in the high calcium specimen (VKL-133) and maximum iron was associated with only nickel detected in these landbirds.

Six sparrowhawks were obtained from the manager of the Salton Sea National Wildlife Refuge. The small raptor's food-chain is based on animals

Table 8. Trace element concentrations in livers from aquatic birds collected in the Imperial Valley.

ug/g dry weight (ppm)															
Date	Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
2 September 1975	Cattle Egret	VKL-157	12140	291.5	13.2	2104	0.9	20.8	83.8	ND ^a	6.9	1.8	ND	ND	ND
		VKL-158	11780	359.1	14.5	1335	0.7	23.0	89.0	1.0	3.4	1.8	1.0	ND	ND
		VKL-159	12160	206.9	13.0	2161	1.0	21.3	88.7	ND	4.9	1.4	2.2	ND	ND
		VKL-170	13320	351.2	17.0	3517	1.7	22.4	109.8	ND	3.5	1.3	2.3	ND	ND
		VKL-171	11250	207.7	14.0	2155	1.2	24.5	86.9	ND	5.6	1.8	ND	ND	ND
		VKL-172	13520	1060.0	13.2	3365	1.5	21.9	89.9	1.3	9.6	3.9	1.9	3.5	ND
9 February 1976	Calif. Gull	VKW-148	10160	263.1	ND	2752	ND	11.1	78.5	ND	4.1	4.5	5.2	0.9	ND
		VKW-149	9367	161.0	ND	1258	ND	11.0	71.0	ND	7.9	4.9	9.9	0.6	ND
		VKW-150	8571	395.4	ND	1095	ND	11.1	71.8	ND	11.5	7.7	5.5	1.8	ND
		VKW-151	10050	427.1	ND	919	ND	12.4	89.7	ND	7.3	6.6	9.1	2.8	ND
		VKW-152	10130	389.8	ND	1376	ND	16.1	79.1	ND	6.6	9.7	8.4	3.4	ND
		VKW-153	10460	389.1	ND	1278	ND	13.2	80.3	ND	7.0	5.2	10.6	2.2	ND
15 February 1976	Gt. Blue Heron	VKL-174	13050	232.5	16.0	2913	1.6	22.3	52.4	1.2	11.3	11.1	11.7	ND	ND
	Brown Pelican	VKW-175	13150	445.8	11.1	1157	ND	35.7	252.5	ND	4.3	16.1	ND	ND	ND

^a Not detected

Table 9. Trace element concentrations in livers from land birds collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As ^b	Se	Br	Rb	Sr
22 November 1975	Pheasant-Phasianus colchicus	VKL-133	11770	776.5	ND ^a	482	ND	12.3	107.5		2.2	3.7	4.1	1.9
		VKL-142	11060	46.1	10.1	803	0.6	17.3	106.5		2.0	4.9	9.5	ND
		VKL-143	10700	ND	7.5	404	ND	15.8	86.9		2.4	3.0	2.0	ND
14 February 1976	Roadrunner - Geococcyx californianus	VKL-160	11260	208.6	18.3	650	0.5	18.2	116.4		11.2	6.4	4.3	ND
		VKL-161	13130	149.7	16.9	403	ND	21.1	128.4		9.0	4.3	4.6	ND
		VKL-164	12440	187.1	11.6	906	0.7	15.0	89.3		4.0	6.6	3.6	ND
		VKL-165	10530	317.9	16.4	1142	0.7	21.4	104.2	1.3	9.4	9.2	4.6	ND
13 February 1976	Sparrowhawk-Falco sparverius	VKL-154	8205	235.8	ND	1539	ND	23.8	79.7		4.2	4.2	3.9	1.8
		VKL-155	12050	1892.0	7.0	438	ND	15.0	71.0		3.6	4.7	2.2	ND
		VKL-156	7188	ND	ND	320	ND	26.0	94.6	2.7	3.4	2.2	1.7	ND
		VKL-157	9536	579.0	12.5	699	ND	26.2	103.0	5.8	5.5	4.8	2.4	ND
		VKL-158	12130	721.0	13.5	418	0.6	20.0	98.8		5.0	6.2	4.2	1.3
		VKL-159	9637	1354.0	7.5	705	ND	25.8	81.3		5.2	4.6	4.6	5.7

^a Not detected

^b Detected only in roadrunner and sparrowhawks

in roadside and field habitats. Each sparrowhawk contained selenium in its liver and five out of six had strontium. The other organs of the sparrowhawks contained elevated lead concentrations that can be correlated with the deposition of automotive lead in the roadside environment.¹⁹

The data on Sacramento Valley waterfowl collections and the trace element analyses of livers are presented in Table 10. These birds were obtained on the 22 November 1975, within two months after the major influx of wintering waterfowl arrived at the Sacramento National Wildlife Refuge. The presence of selenium in all animals suggests that the animals had equilibrated with the local sources of this element. It is possible that animals arrive at the wintering grounds with these selenium concentrations, having acquired them from habitats on the migratory routes to California, but this is unlikely. Almost all the waterfowl spend too little time in the flyway habitats to acquire the local trace elements, unless a source is particularly strong. Some species of waterfowl fly non-stop from breeding areas to the wintering grounds. When we obtain data on waterfowl that have had no contact with southern environments, i.e., collected from the breeding areas, some of these questions may be resolved. The only occurrence of lead in snowgeese, sample VKG-534, was accompanied by maximum iron, nickel, and selenium concentrations. The lead concentration (58.7 ppm) is in the range producing toxic and lethal effects. Bromine concentrations in the shoveler duck were higher (57.5 ppm vs 30.6 ppm) than in the green-wing teal, suggesting a relationship between bromine and the feeding behavior of the shoveler duck.

The trace element concentrations determined in the livers of green-wing teal ducks collected at the Sacramento National Wildlife Refuge area (Table 10) are apparently the same in this small series of samples as in species

Table 10. Trace element concentrations in livers from waterfowl collected in the Sacramento Valley on 22 November 1975.

ug/g dry weight (ppm)													
Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr
Snowgoose	VKG-501	11420	165.8	19.4	2720	1.3	186.7	212.3	5.6	30.1	8.7	ND ^a	ND
	VKG-523	8306	241.1	16.6	1158	0.8	123.1	196.8	1.6	21.4	6.5	ND	ND
	VKG-533	10520	176.4	14.4	2013	1.1	179.4	163.0	6.0	15.1	7.5	ND	ND
	VKG-534	8946	113.2	13.8	4994	1.8	54.9	110.1	7.5	16.2	8.7	ND	58.7
Green-winged	VKD-504	7717	141.9	ND	1584	ND	88.0	99.9	3.8	17.9	3.8	ND	ND
Teal	VKD-508	8431	110.7	ND	771	ND	33.2	45.8	1.5	14.7	30.0	ND	ND
	VKD-516	8761	146.7	4.8	1825	ND	182.7	135.5	0.9	21.9	15.8	ND	ND
	VKD-517	5138	ND	ND	478	ND	28.5	42.2	0.7	8.6	10.5	ND	ND
	VKD-518	6983	2138.0	11.2	476	ND	49.4	53.4	1.2	14.5	82.8	17.9	ND
	VKD-522	7381	85.8	ND	842	ND	107.2	90.7	1.1	20.9	14.7	ND	ND
	VKD-530	9414	196.2	ND	2182	ND	64.5	92.3	2.1	115.6	22.2	0.4	ND
	VKD-503	9311	129.3	ND	3282	ND	42.3	85.4	4.4	45.6	11.9	0.3	ND
	VKD-505	10840	502.8	13.0	1569	ND	84.1	133.1	6.7	76.2	5.5	0.8	ND
Shoveler Duck	VKD-506	9136	178.3	16.4	1751	ND	55.7	109.5	5.0	68.6	9.4	0.6	ND
	VKD-507	8694	279.3	12.6	1632	ND	84.2	120.2	7.4	39.9	4.9	1.0	2.1
	VKD-509	9506	140.3	9.6	3272	ND	65.8	126.7	5.3	88.3	5.0	ND	ND
	VKD-512	9105	206.1	10.4	2576	ND	68.3	116.4	5.8	48.2	7.6	ND	4.9
	VKD-519	9217	191.8	10.3	5789	ND	23.1	97.9	5.4	68.5	11.6	ND	ND
	VKD-524	9146	128.8	10.1	5562	ND	55.0	90.4	3.6	35.5	5.5	ND	6.7
	VKD-535	8962	236.8	ND	2826	ND	32.2	101.5	4.9	54.0	5.6	0.4	ND
	VKD-536	9697	166.8	4.9	2738	ND	73.3	114.2	4.4	59.9	9.4	0.3	ND
	VKD-537	9260	217.0	ND	3091	ND	56.8	82.4	3.2	48.1	4.8	ND	ND
	VKD-514	12400	289.2	35.2	3827	2.2	69.5	274.2	2.5	17.6	8.0	ND	2.5
Pintail Duck	VKD-520	9653	79.6	18.7	3465	1.6	134.6	194.5	4.7	11.9	7.7	ND	44.6
Mallard duck	VKD-515	10700	201.5	ND ¹	4145	ND	64.2	104.2	2.5	15.7	38.8	ND	0.8
	VKD-525	7352	139.9	ND	1546	ND	123.0	119.7	3.6	20.8	26.0	ND	ND
	VKD-526	8198	96.0	ND	1638	ND	207.1	141.3	1.4	17.7	28.0	ND	ND
	VKD-527	7240	106.9	ND	2311	ND	52.4	72.2	2.9	35.7	26.1	ND	ND
	VKD-529	7086	ND	ND	1715	ND	69.1	69.5	1.5	22.4	30.1	ND	ND

^a Not detected

noted in the previous paragraph. The maximum calcium concentration is accompanied by the highest rubidium and strontium concentration observed, and this suggests that alkaline earth elements (not Rb) are absorbed as a group rather than individually. This was observed in physiological studies of the radioisotope, ^{90}Sr , in animals and man.²⁰ A low potassium value in sample VKD-517 is correlated with the lowest iron, copper, zinc, selenium, and bromine; no calcium and manganese were detected. These low levels of essential elements suggest a poor state of health of the birds and may be indicative of disease or other physiological problems.

An analysis of trace elements in livers of shoveler ducks from the Sacramento National Wildlife Refuge area yielded no nickel or arsenic (Table 10). Strontium occurred in 54% of the animals analyzed; three had low levels of lead and maximum potassium, calcium, copper and zinc occurred in one animal. Livers of pintail ducks collected at the same wildlife refuge contained lead (Table 10), one at a toxic level (44.6 ppm).

The livers of mallard ducks collected at the same location (Table 10) had the usual required elements--potassium, calcium, iron, copper, zinc, and three non-essential elements--bromine, rubidium, and lead. All had low levels of selenium and no strontium.

Kidneys

Kidneys from pintail ducks collected in the Imperial Valley were analyzed (Table 11) and selenium was found in all animals; however, nickel occurred in 87%, arsenic in 19% strontium in 9%, and lead in 41%. The correlation between calcium and strontium and iron and nickel was seen here as well.

The highest lead concentration (67.8 ppm) was related to high rubidium and arsenic and low zinc, calcium, and potassium. This high value of lead

Table 11. Trace element concentrations in kidneys from pintail ducks (*Anas acuta*) collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr ^b	Pb
23 October 1975	VKD-004	11980	192.4	14.4	539	0.5	32.1	100.0	ND ^a	9.7	32.5	16.1		ND
	VKD-007	12740	338.6	13.0	489	0.6	18.3	83.7	ND	6.5	18.3	15.1		ND
	VKD-009	13800	342.8	11.3	434	0.8	43.4	114.3	ND	5.1	18.8	9.3		ND
	VKD-012	14060	217.3	13.1	653	ND	20.5	99.7	ND	6.7	9.3	8.5		ND
	VKD-015	8400	167.5	9.6	213	0.6	23.7	85.2	ND	7.0	5.8	3.4		ND
	VKD-022	13870	260.5	13.9	484	ND	30.0	97.6	0.9	13.0	8.6	14.0		ND
	VKD-027	11670	305.8	14.8	499	0.5	20.3	107.0	1.6	13.8	15.6	13.0		ND
	VKD-028	12990	354.9	14.4	475	0.6	23.3	117.3	ND	9.4	15.4	19.5		ND
1 November 1975	VKD-103	11670	242.2	8.0	582	0.5	21.7	85.2	ND	9.4	17.5	16.3		ND
	VKD-042	14400	315.0	16.3	327	0.7	42.3	100.0	ND	6.8	13.1	4.6		9.0
	VKD-045	9379	ND	9.1	574	ND	22.3	79.1	ND	8.0	17.0	10.5	0.7	2.3
	VKD-046	10590	212.5	10.8	471	0.6	32.2	82.9	0.9	6.5	31.2	7.6		ND
	VKD-047	14700	304.2	15.8	823	0.8	43.4	104.8	1.1	7.0	14.6	12.8		ND
	VKD-049	9895	224.3	12.4	381	ND	29.3	86.5	ND	3.6	5.9	10.7		ND
	VKD-050	12790	270.7	14.5	550	0.5	35.6	102.1	ND	5.4	7.6	11.9		ND
	VID-051	11850	244.4	9.8	640	0.5	32.7	85.0	ND	8.3	16.9	13.2		ND
	VKD-053	8627	181.7	11.6	498	0.6	18.8	70.7	4.3	12.6	11.4	21.2		67.8
	VKD-057	8933	242.0	7.1	737	0.5	12.8	75.9	ND	10.3	21.5	3.0		ND
	VKD-066	15040	284.5	12.5	712	0.5	33.4	109.7	ND	10.7	16.3	6.5		1.7
	VKD-067	10570	277.1	7.8	560	0.6	42.9	87.9	ND	4.5	11.0	19.6		5.8
	VKD-079	11330	270.9	13.4	496	0.7	38.3	107.3	ND	15.2	24.1	7.7		2.1
	VKD-084	12290	155.8	11.0	660	0.5	33.9	97.3	ND	11.8	14.1	11.8		ND
	VKD-086	13550	205.1	18.7	608	0.6	31.1	116.0	1.5	28.7	26.0	6.4		1.8
	VKD-090	12650	225.9	14.6	515	0.6	24.5	100.3	ND	12.9	14.0	7.5		1.2
17 January 1976	VKD-093	10170	372.9	13.9	584	0.6	46.1	136.5	ND	15.7	14.7	7.8		ND
	VKD-102	11790	198.0	14.9	886	0.9	34.4	102.5	ND	19.3	12.3	15.7		ND
	VKD-106	12310	1363.0	16.9	509	0.6	25.4	103.9	ND	15.0	10.1	5.6	13.8	2.3
	VKD-108	12880	766.2	12.7	616	0.7	26.4	100.0	ND	6.2	13.5	11.1	3.2	5.2
	VKD-114	12410	254.7	13.2	577	0.6	27.7	102.6	ND	13.5	12.4	6.0		ND
	VKD-118	10630	187.0	13.4	653	0.5	23.0	81.4	ND	21.9	8.7	4.8		0.9
	VKD-119	12720	199.4	14.3	407	0.6	40.8	118.5	ND	8.6	14.7	15.5		2.9
	VKD-124	13660	235.0	14.7	647	0.7	35.0	111.7	ND	16.5	13.0	4.7		4.3

^a Not detected^b Detected only in VKD-045, VKD-106, and VKD-108

(VKD-053) was not accompanied by the presence of lead in the liver (see Table 1). Lead appeared in both liver and kidney in only two pintail ducks (VKD-119 and VKD-124) with higher values present in both animals in the kidneys. It is possible at these contamination levels the kidney may be still excreting lead whereas it has already cleared the liver. Tenacious binding sites in the kidney are known to occur for metals such as lead, cadmium, and mercury.²¹

Nickel occurred in 93% of the shoveler duck kidneys analyzed (Table 12). The highest lead concentration (21.8 ppm), in VKD-115, was accompanied by a concentration of 5.9 ppm in the liver (Table 3) and the highest strontium concentration (3.0 ppm) in the kidney was correlated with the only strontium observed in the livers (Table 3).

All kidneys of ruddy ducks from the Imperial Valley contained nickel and selenium (Table 13). The highest lead concentration measured in this study was observed in sample VKD-121 (886.3 ppm) and was correlated with the maximum selenium, arsenic, iron, and nickel, and the lowest potassium concentration. The concentration of lead in both VKD-121 and VKD-120 (403.1 ppm) were in the lethal range, and that in VKD-123 (70.3 ppm) could be assumed toxic also. The two highest lead concentration (886.3 and 403.1 ppm) were associated with the highest selenium and arsenic concentration in both birds. Because of the known biochemical behavior of selenium as an anti-oxidant²², it is possible that a protective action against lead toxicity may be effected when selenium is present at these levels. The sources of lead and selenium in this environment are believed to be different, and therefore accumulation was either independent or one stimulated the other. It is possible that the age of the animal is in part

Table 12. Trace element concentrations in kidneys from shoveler ducks (*Anas clypeata*) collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As ^a	Se	Br	Rb	Sr ^b	Pb ^c
23 October 1975	VKD-011	9909	442.4	9.9	1577	1.0	38.8	85.2		12.2	45.0	8.3	0.7	3.5
	VKD-023	11180	197.9	12.7	496	0.6	18.0	99.2		17.9	39.4	8.8		
1 November 1975	VKD-031	12120	262.6	10.3	843	0.6	13.2	75.6		11.2	65.6	7.7		
	VKD-065	11780	276.2	9.8	664	0.5	21.9	94.0		81.1	62.4	4.4		
17 January 1976	VKD-073	13170	457.2	13.0	455	0.5	14.6	109.2		9.9	9.0	17.5	3.0	3.5
	VKD-077	13690	748.3	11.5	385	0.7	28.3	101.4		19.7	78.1	2.6	1.4	
	VKD-079	11860	275.2	10.1	752	0.6	14.8	96.3		8.1	14.0	10.6		
	VKD-085	11550	187.9	11.1	745	1.0	19.4	89.9		18.1	46.7	10.3		
	VKD-088	12630	150.5	10.6	305	ND ^d	21.0	114.7	0.9	13.5	15.5	15.6		
	VKD-091	11900	239.1	11.2	577	0.6	19.3	133.3		12.5	11.7	22.6		
	VKD-098	12690	280.9	10.2	540	0.7	30.1	124.6	1.9	20.0	91.5	10.4		
	VKD-111	13720	288.4	12.8	519	0.7	21.7	97.5		9.8	17.2	15.2		
	VKD-112	13500	279.8	11.5	639	0.7	14.7	97.8		9.0	8.8	25.1		
	VKD-115	12940	268.2	10.9	569	0.7	31.2	155.5		15.3	26.2	14.5		21.8
	VKD-116	14810	241.5	12.8	531	0.7	21.0	128.3	1.1	8.3	12.4	31.3		

^a Detected only in VKD-088, VKD-098, and VKD-116

^b Detected only in VKD-011, VKD-073, and VKD-077

^c Detected only in VKD-011, VKD-073 and VKD-115

^d Not detected

Table 13. Trace element concentrations in kidneys from ruddy ducks (*Oxyura jamaicensis rubida*) collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As ^a	Se	Br	Rb	Sr ^b	Pb ^c
23 October 1975	VKD-005	13210	292.0	17.9	826	0.6	27.8	98.8		29.4	16.4	4.9		2.3
	VKD-020	12050	257.0	13.7	834	0.6	34.6	86.4		17.3	10.9	5.4		
	VKD-021	13170	261.5	11.2	698	0.7	15.4	93.6	1.1	12.7	10.6	4.5		
1 November 1975	VKD-036	13790	269.9	14.6	684	0.6	16.8	88.3		12.6	16.4	3.5		
	VKD-064	14620	264.7	13.4	612	0.5	15.2	91.8		26.5	12.8	4.5		
	VKD-069	12860	264.6	14.6	593	0.5	17.3	88.1		28.9	10.8	5.4		
18 January 1976	VKD-120	14420	753.2	21.7	785	1.0	19.0	82.9	4.7	161.3	9.6	1.9		403.1
	VKD-121	11540	378.4	15.4	845	1.7	18.0	91.5	11.9	294.2	10.8	1.2		886.3
	VKD-122	10470	216.0	12.3	595	0.6	13.2	95.9		23.2	9.0	4.7		3.0
	VKD-123	13790	500.4	17.9	444	0.6	15.2	90.7		99.7	8.3	3.8	1.3	70.3

^a Detected only in VKD-021, VKD-120, and VKD-121

^b Detected only in VKD-123

^c Detected only in 22 October 1975 and 18 January 1976 animals

related to the concentration of substratum-derived trace elements such as selenium and arsenic; however, lead uptake could occur in any age group because of the usual mode of ingestion.

Sample VKD-121 with 886.3 ppm lead in the kidney had 97.3 ppm in the liver (liver/kidney ratio = 0.11); while sample VKD-120 had a ratio of 0.51 and sample VKD-123 one of 0.44. It is possible that these ratios may indicate the status of an animal's lead contamination as it eliminates lead from physiological and biochemical compartments. The birds with the large quantities of lead, discussed above, had no external signs of poor health nor gross internal symptoms. If the sample body weights were available, they would be useful in detecting the general wasting of muscle mass and weight loss associated with lead toxicity.

The kidneys from green-winged teals in the Imperial Valley were analyzed (Table 14) and 38% had nickel, 20% had arsenic, 100% had selenium and bromine, 97% had rubidium, 56% had strontium, and 59% had lead. The green-winged teal ducks were collected at three different times, 23 October 1975 (VKD-011-037), 1-2 November 1975 (VKD-038-063), 17 January 1976 (VKD-081-110), spanning most of this wintering period in the Imperial Valley. In the October 1975 samples the mean concentration of selenium in the kidney was 12.8 ppm, in the November 1975 samples it was 14.3 ppm, and in the January 1976 samples the mean selenium value was 19.8 ppm. These selenium concentrations suggest that a gradual increase of trace elements occurs as waterfowl winter in the valley.

In addition, almost 100% of January 1976 samples contained nickel, but in the earlier samples only 16.7% of the birds contained detectable nickel. Bromine concentrations in the kidneys also increased during the wintering

Table 14. Trace element concentrations in kidneys from green-winged teal (*Anas crecca*) collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
23-24 Oct. 1975	VKD-001	10330	319.4	ND ^a	526	ND	14.8	82.1	ND	13.3	20.8	12.4	1.4	1.3
	VKD-003	9035	ND	ND	482	ND	33.7	98.8	ND	8.7	10.7	9.8	1.2	ND
	VKD-006	6679	ND	ND	366	ND	28.0	97.9	ND	9.0	11.6	8.3	ND	ND
	VKD-013	13090	228.9	13.5	886	0.6	32.0	93.2	ND	11.3	33.4	9.6	ND	2.0
	VKD-016	6822	ND	ND	500	ND	35.1	93.3	ND	13.6	13.0	7.5	ND	ND
	VKD-019	12800	196.5	17.0	310	ND	21.8	100.7	1.6	10.6	14.7	7.5	ND	ND
	VKD-024	13240	316.3	16.6	404	0.6	17.3	94.1	ND	10.7	17.2	4.9	ND	10.9
1-2 November 1975	VKD-026	12450	264.4	12.7	351	ND	21.2	105.8	ND	11.8	17.1	10.3	ND	ND
	VKD-032	13760	193.2	16.6	372	0.8	29.3	104.1	1.5	16.1	18.3	6.6	ND	ND
	VKD-033	11660	203.1	16.5	557	0.8	21.7	92.3	1.2	13.2	9.8	5.9	ND	ND
	VKD-034	12670	215.1	13.0	534	ND	32.6	103.2	ND	22.0	15.8	5.4	ND	ND
	VKD-035	11550	278.4	ND	348	ND	20.3	102.0	ND	15.0	11.8	11.2	0.9	1.7
	VKD-037	11280	317.3	16.2	384	ND	19.6	83.4	ND	11.6	12.6	5.1	1.1	11.8
	VKD-038	10580	250.2	ND	417	ND	20.8	95.0	ND	15.3	8.9	6.6	1.3	1.6
	VKD-043	11670	287.7	ND	351	ND	18.8	88.5	ND	15.8	20.3	10.7	1.2	1.4
	VKD-052	11430	516.4	ND	761	ND	17.5	95.7	ND	15.7	14.6	ND	1.9	2.1
	VKD-054	10110	241.3	ND	705	ND	19.3	78.5	ND	13.3	18.0	3.6	0.9	1.0
	VKD-055	10730	282.9	ND	568	ND	42.1	103.0	ND	15.9	14.0	6.5	1.4	2.3
	VKD-056	10880	299.6	ND	1027	ND	33.5	100.7	ND	12.7	17.5	15.6	0.9	1.7
	VKD-058	10670	278.7	ND	543	ND	30.6	102.0	ND	16.0	23.3	6.8	1.1	1.7
	VKD-059	10010	287.3	ND	517	ND	15.7	77.6	ND	12.2	14.8	10.0	2.7	1.3
	VKD-060	11710	249.0	ND	442	ND	18.9	84.4	ND	13.7	21.8	8.8	0.8	1.5
	VKD-062	9679	430.7	ND	486	ND	19.1	89.0	ND	10.9	14.7	7.3	2.7	1.4
	VKD-063	11590	256.5	ND	332	ND	21.7	104.7	0.9	16.1	11.4	5.3	1.3	1.8
17 January 1976	VKD-082	11580	198.4	16.9	556	0.9	42.3	110.9	1.2	23.1	29.1	6.9	ND	ND
	VKD-087	11850	217.4	18.1	451	0.6	39.5	107.5	1.4	41.7	24.7	7.2	ND	2.0
	VKD-089	11520	421.4	19.8	487	0.6	29.3	116.2	ND	26.8	90.1	6.2	ND	20.1
	VKD-092	12230	727.5	17.4	433	ND	26.5	118.2	ND	14.5	39.2	11.8	ND	ND
	VKD-095	12560	447.6	13.2	485	0.7	13.8	94.4	ND	10.8	29.0	18.2	2.7	ND
	VKD-096	7842	523.3	13.1	477	0.8	11.2	68.9	ND	8.3	41.8	15.9	5.9	ND
	VKD-097	11310	396.3	18.5	534	0.6	25.1	105.1	ND	17.0	44.1	5.8	2.4	15.4
	VKD-101	11040	284.9	21.8	468	0.6	31.7	110.2	ND	24.8	5.9	6.9	2.5	ND
	VKD-110	12140	164.5	12.0	854	0.6	19.2	82.4	ND	9.4	24.2	6.2	ND	ND

^a Not detected

period (15.6 vs 40.6 ppm). The only occurrence of lead in the green-winged teal liver, VKD-038 (40.6 ppm) (Table 5), was correlated with only 1.6 ppm in the kidney of the same bird (Table 16).

The kidneys of snowgeese collected in the Imperial Valley (Table 15) are characterized by nickel in 89% of the birds and low frequencies of arsenic, strontium, and lead. The maximum lead concentration observed in the kidney of VKG-109 (17.0 ppm) was correlated with a concentration of 4.4 ppm in the liver (liver/kidney ratio = 0.26).

The data on kidneys of Canada geese and California gulls collected in the Imperial Valley (Table 16) present no obvious patterns of trace element distribution. The six gulls were characterized by relatively high concentrations of strontium; the highest of which was correlated with the maximum calcium concentration. No nickel, arsenic, or manganese was detected in their kidneys. The low level of lead in two of the gulls may represent the geochemical level of lead from the substratum because Bowen¹⁶ gives a value of 4.5 ppm for mammalian kidneys. Neither kidney concentration was related to one in the liver. In general, the trace element composition of the gulls' organs suggests a stronger relationship to the terrestrial than to the aquatic environment of the Imperial Valley.

Trace element concentrations in kidneys of miscellaneous species of waterfowl collected in the Imperial Valley are shown in Table 17. Diving ducks in this series are represented by the baldpate, bufflehead, redhead, and goldeneye ducks. The mallard (VKD-041) and the goldeneye (VKD-072) had lead in the kidneys but none was detected in the liver. In contrast, the cinnamon teal (VKD-125) had no detectable lead in the kidney while 5.0 ppm was found in the liver. Maximum iron, manganese, rubidium, and bromine concentrations in VKD-068 were correlated with the low calcium concentration.

Table 15. Trace element concentrations in kidneys from snowgeese (*Chen caerulescens*) collected in the Imperial Valley on 18 January 1976.

ug/g dry weight (ppm)													
Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As ^a	Se	Br	Rb	Sr ^b	Pb ^c
VKG-071	15510	369.2	11.0	731	0.7	15.1	111.3	1.0	4.4	6.9	0.9		
VKG-075	13710	377.9	10.3	1316	0.9	16.7	92.3		4.3	7.5	2.5		
VKG-076	13020	329.5	9.4	873	0.5	29.1	117.5		5.1	10.2	4.0		
VKG-080	13350	303.7	13.6	795	0.7	14.1	83.7		5.1	6.5	3.5	0.9	
VKG-083	15780	313.7	6.0	831	0.6	13.0	96.0		3.6	9.5	3.9		
VKG-099	12350	213.5	7.1	631	0.6	20.5	100.0		4.6	8.1	2.9		
VKG-103	14570	337.8	9.2	676	0.9	18.7	86.0		3.6	6.5	3.8	2.7	
VKG-104	14870	210.8	8.8	558	0.6	16.9	93.2		4.0	7.0	2.7		2.0
VKG-105	14160	224.1	10.4	897	0.6	22.1	117.5		4.5	10.2	1.9		
VKG-107	13440	186.2	10.4	742	0.6	21.8	110.2		4.9	8.7	3.7		5.2
VKG-109	15380	256.0	11.4	527	ND ^c	42.0	124.9		5.4	8.1	3.0		17.0
VKG-113	16150	349.4	10.4	761	0.6	16.6	95.6		4.4	7.8	3.0		
VKG-117	14400	319.2	12.3	893	0.5	29.4	181.9	1.0	6.3	9.4	2.4		1.1
VKG-126	18700	427.3	8.3	489	ND	23.0	109.4		4.7	7.9	2.6		
VKG-127	15680	423.5	8.8	744	0.8	30.5	121.0	1.0	4.6	8.3	0.8		
VKG-128	15970	424.0	9.4	869	0.7	26.7	96.0		4.2	11.6	2.5		
VKG-129	15900	310.2	11.1	671	0.6	18.4	104.5		5.5	10.3	3.4		
VKG-130	14780	344.2	8.6	642	0.5	20.1	102.4		4.4	7.8	1.3		

^a Detected only in VKG-071, VKG-117, and VKG-127

^b Detected only in VKG-080 and VKG-103

^c Detected only in VKG-104, VKG-107, VKG-109, and VKG-117

Table 16. Trace element concentrations in kidneys from Canada Geese and California gulls collected in the Imperial Valley.

ug/g dry weight (ppm)													
Date	Species	Speciman	K	Ca	Mn	Fe	Cu	Zn	Se	Br	Rb	Sr	Pb
1 Nov 1975	Canada	VKG-039	9903	283.9	ND ^a	565	11.8	85.6	4.2	11.9	8.6	0.8	ND ^a
	Goose	VKG-061	8775	250.1	ND	783	15.3	93.4	4.4	10.5	8.2	0.9	0.9
15 February 1976		VKG-140	11810	171.7	8.7	597	12.3	86.2	4.6	6.8	1.3	ND	ND
		VKG-144	9294	170.8	8.0	557	9.9	64.0	3.5	6.1	1.2	ND	ND
		VKG-145	8472	144.6	11.3	334	13.6	78.5	3.6	5.1	1.8	ND	ND
		VKG-146	10010	199.7	ND	829	12.0	66.3	3.7	5.6	2.1	0.5	ND
		VKG-173	12280	384.0	10.1	516	14.6	73.4	1.2	3.0	5.1	ND	ND
		VKG-174	13760	438.7	11.7	488	14.1	96.6	ND	3.6	6.2	ND	ND
	Calif	VKW-148	9550	774.9	ND	659	12.8	98.6	6.0	10.1	6.7	5.5	1.1
	Gull	VKW-149	8553	825.1	ND	448	13.4	88.1	8.7	8.1	8.1	5.1	ND
		VKW-150	8278	622.3	ND	314	12.9	92.8	12.9	11.3	4.5	3.8	ND
		VKW-151	9707	748.7	ND	293	14.3	100.2	8.1	9.4	8.2	4.9	ND
		VKW-152	9548	2086.0	ND	511	17.6	87.0	7.8	15.4	7.4	22.5	ND
		VKW-153	9980	1629.0	ND	829	14.8	92.6	8.2	9.8	10.6	10.8	4.4

^a Not detected

Table 17. Trace element concentrations in kidneys from miscellaneous species of waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Species	Specimen	K	Ca	Mn	Fe	Cu	Zn	As	Se	Br	Rb	Sr	Pb
23 October 1975	Widgeon	VKD-008	10500	200	ND ^a	464	22.4	96.9	ND	8.6	8.3	4.7	0.5	ND
	Baldpate	VKD-017	11400	319	ND	439	19.2	113.0	0.5	13.7	9.8	4.2	1.9	1.1
1 November 1975	Bufflehead	VKD-029	12100	185	ND	316	11.2	94.1	ND	12.7	17.6	7.7	2.7	1.4
	Redhead	VKD-040	11100	186	ND	589	14.3	85.1	ND	6.2	13.7	4.7	1.4	2.2
	Mallard	VKD-041	10200	217	ND	502	26.7	92.5	1.2	10.1	17.9	14.4	1.2	2.2
	Bufflehead	VKD-068	9970	70	6.2	3370	28.9	85.0	ND	5.7	45.2	48.1	1.0	0.5
17 January 1976	Redhead	VKD-070	10250	217	ND	438	17.1	105.0	ND	3.7	24.7	12.8	1.4	ND
	Goldeneye	VKD-072	10220	162	ND	536	14.6	81.4	ND	8.5	8.7	13.4	0.7	5.0
	Cinnamon Teal	VKD-074	9350	249	ND	524	23.6	93.3	0.7	9.3	28.0	13.6	1.9	ND
	Cinnamon Teal	VKD-125	9720	305	5.8	2200	65.9	112.0	0.3	5.8	16.0	8.2	1.9	ND

^a Not detected

The trace element concentrations in the kidneys of various land birds from the Imperial Valley (Table 18) such as pheasants, roadrunners, and sparrowhawks are representative of granivorous, scavenging, and raptorial feeding behavior. This range of feeding behavior embraces a wide spectrum of ecological niches and relationships with the substratum and local food organisms. Kidneys of the roadrunner contain fewer trace elements than those of waterfowl. Manganese, nickel, arsenic, and strontium were not detected. However, selenium, bromine, and rubidium were at approximately the same level as in waterfowl. Lead occurred only in the kidneys of VKL-164 (9.6 ppm) and was correlated with 1.7 ppm lead in its liver (Table 9). The most obvious source of lead in this species is lead deposited from automobiles along roadways where this bird is observed scavenging.

The kidneys of four pheasants analyzed in this group of birds showed some previously observed relationships. Only one pheasant had a high level of calcium (1494.0 ppm), and it was also the only bird having detectable strontium. Nickel was found in the birds having the highest iron concentration. Lead was not detected in the livers of the same three birds that had this element in their kidneys (Tables 9 and 18). The presence of any lead in the pheasants suggests that these birds fed either in roadside habitats and obtained grit from the edges of roads or ingested lead shot. Spent lead shot is a possible source of lead for pheasants, especially in heavily hunted areas such as the Imperial Valley.²⁴

The six sparrowhawk kidneys contained no manganese, nickel, or arsenic. Strontium was found in 66% and selenium in 83% of the birds, which suggests a relationship with the Imperial Valley soils that have relatively high concentrations of these elements. As in the pheasants, no lead was found in

Table 18. Trace element concentrations in kidneys from land birds collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Species	Specimen	K	Ca	Mn ^b	Fe	Ni ^c	Cu	Zn	Se	Br	Rb	Sr	Pb
2-13 February 1976	Sparrowhawk <i>Falco sparverius</i>	VKL-154	2244	ND ^a		390		50.1	87.3	ND	6.5	3.4	ND	ND
		VKL-155	5390	ND		311		33.7	66.9	2.6	10.2	5.5	ND	ND
		VKL-156	7292	ND		661		38.3	100.4	2.9	7.1	2.2	4.0	93.4
		VKL-157	9813	747.0		458		22.3	95.4	7.7	9.8	6.7	4.9	ND
		VKL-158	5328	634.0		422		11.3	80.3	5.3	9.8	7.2	5.9	ND
		VKL-159	2481	253.9		352		28.7	60.9	4.2	7.4	4.3	8.3	37.8
16 February	Pheasant <i>Phasianus colchicus</i>	VKL-133	11820	1494.0		693		11.1	92.6	3.3	7.2	4.4	1.8	2.3
		VKL-141	9578	236.5	5.4	829	0.5	10.3	59.6	3.7	5.7	2.8	ND	10.9
		VKL-142	12040	187.5	11.4	381		16.2	83.8	4.1	7.0	9.5	ND	4.6
		VKL-143	9890	554.2	5.3	670	0.7	10.9	70.9	2.9	6.5	1.0	ND	ND
Feb.-Mar. 1976	Roadrunner <i>Geococcyx californianus</i>	VKL-160	8030	ND		343		26.8	80.5	6.6	10.6	5.5	ND	ND
		VKL-162	10590	543.0		574		23.8	76.4	8.5	11.9	5.7	ND	ND
		VKL-164	10000	ND		446		22.5	71.1	5.4	12.0	4.4	ND	ND
		VKL-165	7872	ND		346		20.2	69.6	7.9	10.9	6.3	ND	ND

^a Not detected

^b Detected only in VKL-141, VKL-142, and VKL-143

^c Detected only in VKL-141, and VKL-143

the livers of the two birds having lead in the kidneys. The highest lead concentration (93.4 ppm) was correlated with the maximum zinc and iron. Lead toxicity is known to increase the storage of these metals. The presence of lead from automobiles in roadside animals, and the sparrowhawk is often seen hunting small rodents and birds that inhabit roadside habitats, has been documented by several investigators.¹⁹

The kidneys of twelve shoveler ducks from the Sacramento Valley are characterized by the absence of manganese, nickel, and arsenic (Table 19). Four low concentrations of lead in the kidneys showed no correlation with lead detected in the liver (Table 10) but the highest lead concentration (6.2 ppm) was related to a liver concentration of 4.9 ppm. Two high concentrations of bromine in the shoveler duck kidneys were highest detected in this study.

Kidneys from the green-wing teal (Table 20), also collected in the Sacramento Valley, had the maximum concentration of potassium, calcium, rubidium, strontium, and lead in the same bird. The only manganese and nickel detected was also in this duck. The kidney lead (4.8 ppm) was not correlated with the presence of lead in the liver of the same bird. All of these ducks were obtained late in November 1975, approximately two months after the arrival of wintering waterfowl.

Two snowgeese obtained in the Sacramento Valley (Table 20) had no detectable arsenic or strontium in the kidneys. The high lead value in the kidney (142.7 ppm) was correlated with a concentration of 58.7 ppm in the liver, and it is quite apparent that this bird (VKG-534) has ingested a concentrated source of lead, most likely spent shot.^{18,25}

Table 19. Trace element concentrations in kidneys from shoveler ducks (*Anas clypeata*) collected in the Sacramento Valley.

ug/g dry weight (ppm)										
Specimen	K	Ca	Fe	Cu	Zn	Se	Br	Rb	Sr	Pb
VKD-503	11010	215.5	441	21.9	79.8	5.8	53.8	14.7	0.5	0.8
VKD-505	11100	337.9	443	20.4	92.1	6.6	118.4	7.3	0.5	0.9
VKD-506	11710	306.1	339	18.0	87.5	5.6	89.9	13.0	1.2	ND ^a
VKD-507	10840	307.6	555	13.9	82.9	5.2	36.3	14.0	0.3	ND
VKD-509	11140	239.5	374	21.1	96.8	7.0	148.1	6.6	ND	ND
VKD-512	10760	205.9	659	17.6	80.9	6.7	66.5	9.7	0.9	6.2
VKD-519	10200	330.8	472	25.1	80.2	6.5	90.1	15.0	0.7	ND
VKD-524	10750	236.8	522	22.2	95.1	5.9	61.1	8.0	0.7	ND
VKD-535	10700	384.5	449	22.6	86.8	5.4	66.4	6.2	0.9	ND
VKD-536	10670	185.1	484	22.3	99.8	6.1	81.6	13.5	0.4	0.8
VKD-537	10950	367.3	845	12.3	68.5	4.0	61.9	6.2	1.3	ND
VKD-539	10630	255.6	641	15.4	79.0	5.4	68.4	6.4	0.5	0.8

^a Not detected

Table 20. Trace element concentrations in kidneys from waterfowl collected in the Sacramento Valley.

ug/g dry weight (ppm)													
Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Pb
Gr.-winged teal	VKD-504	11510	361.6	ND ^a	556	ND	20.3	87.6	5.2	25.2	7.2	0.5	3.1
	VKD-508	10940	356.7	ND	484	ND	20.9	104.8	5.7	33.7	59.2	ND	ND
	VKD-516	11260	319.9	ND	544	ND	28.4	96.1	11.8	33.6	25.6	1.0	1.4
	VKD-517	11940	1063.0	ND	342	ND	31.7	101.3	4.0	21.6	28.5	1.6	ND
	VKD-518	12170	1118.0	10.5	516	1.1	20.3	95.7	4.8	36.8	154.0	6.8	4.8
	VKD-522	11600	266.2	ND	415	ND	18.7	83.5	2.8	41.4	23.8	ND	ND
	VKD-530	10500	306.2		800	ND	16.0	71.9	2.9	124.1	32.8	0.4	0.7
Pintail	VKD-514	9736	190.4	14.1	591	0.6	44.8	90.2	3.7	21.3	8.3	ND	3.4
	VKD-520	12200	220.6	12.2	430	0.6	32.7	95.6	10.8	22.4	15.1	ND	60.2
Snowgeese	VKG-523	10650	149.7	6.0	960	0.6	12.5	73.3	1.0	19.9	7.4	ND	ND
	VKG-534	7684	195.5	7.4	966	0.9	16.2	67.7	6.6	21.1	9.9	ND	142.7

^a Not detected

The two pintail ducks obtained in the Sacramento Valley (Table 20) were such a small sample that few observations on the species can be made. Both ducks had lead in the kidney and one animal (VKD-520) had 60.2 ppm, which is in the range of toxic effects.

Muscle, Heart, Lung, and Brain

Sparrowhawks and pheasants were collected in the Imperial Valley and their muscles analyzed (Table 21). Muscle samples from both species contained elevated lead concentrations. These samples also had low levels of selenium and nickel. Lead in the sparrowhawk most likely originates in its foodchain, which may be exposed to automobile exhaust lead deposited along roadsides where this small raptor often obtains its prey. The two analyses of pheasant muscle showed the presence of 12.6 ppm of lead in one bird (VKL-141) which correlated with a kidney concentration of 10.9 ppm (Table 18).

Heart samples from pintail ducks and snowgeese from the Imperial Valley contained no lead (Table 22), although three of the pintail ducks (VKD-045), 119, and 124) had lead in the kidneys (Table 11). The hearts also had low levels of selenium and nickel, but no detectable arsenic or strontium.

Analyses of lungs from these ducks and geese (Table 23) yielded relatively high levels of bromine in the pintail ducks and a uniform low level of nickel in both species. The lungs from VKD-007 and VKD-045 contained lead; however, only one of these ducks (VKD-045) had lead in other organs (Tables 1 and 11). This low level of lead in the lungs could be deposited from lead in the vascular circulation, not necessarily from an inhalation pathway. The highest concentration of bromine, however, occurs in the lungs and this suggests that inhalation may be a significant route of uptake for this halogen.

Table 21. Trace element concentrations in muscle from land birds collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb	Sr	Pb
Fall 1975	Sparrowhawk	VKL-154	10460	382.0	ND ^a	77	0.5	18.9	86.0	1.2	3.3	3.1	ND	2.2
		VKL-155	11070	675.6	ND	82	0.7	18.5	88.3	0.9	5.9	3.0	ND	2.4
		VKL-156	13190	1061.0	2.3	115	0.9	16.4	106.9	1.4	3.9	1.4	ND	68.8
		VKL-158	13160	568.8	3.1	102	0.5	14.6	102.7	1.1	6.2	4.5	ND	69.7
		VKL-159	13610	497.2	ND	84	ND	14.3	114.4	0.9	4.2	3.2	ND	ND
	Pheasant	VKL-141	16760	161.6	ND	129	0.5	21.3	48.7	6.0	3.1	2.2	ND	12.6
		VKL-143	19180	3282.0	ND	75	ND	3.9	97.2	1.5	1.2	2.0	5.7	ND

^a Not detected

Table 22. Trace element concentrations in hearts from waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)											
Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb
Snowgoose - <i>Chen caerulescens</i>											
	VKG-105	13450	133.0	2.0	380	0.5	19.8	96.3	2.1	6.8	1.6
Pintail - <i>Anas acuta</i>											
	VKD-007	9445	94.2	ND ^a	228	ND	12.0	51.4	1.2	12.3	9.4
	VKD-009	10700	82.5	2.2	300	0.8	15.3	69.8	0.8	10.6	5.1
	VKD-045	10190	ND	2.1	271	ND	16.6	66.2	4.3	10.9	6.9
	VKD-048	13050	89.0	1.8	318	0.4	19.6	79.6	3.3	13.1	4.9
	VKD-119	11180	37.8	1.6	248	ND	17.8	76.9	1.4	8.2	6.6

^a Not detected

Table 23. Trace element concentrations in lungs from waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)

Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb	Sr	Pb
Pintail Duck	VKD-004	11240	307.7	2.8	1507	0.9	5.4	37.8	5.0	53.6	73.3	ND ^a	ND
	VKD-007	11960	598.8	2.0	1367	0.9	3.0	45.9	6.9	30.2	5.9	1.6	1.8
	VKD-009	13910	663.9	3.6	1372	0.9	4.4	52.0	1.8	30.1	5.5	ND	ND
	VKD-044	11780	586.3	1.6	1288	0.9	4.1	51.4	10.8	44.5	3.7	1.2	ND
	VKD-045	8869	461.1	ND	997	ND	4.3	43.5	5.1	27.8	6.4	2.3	1.6
	VKD-048	12980	480.7	2.9	1438	0.7	3.0	45.5	4.3	31.7	4.3	ND	ND
	VKD-118	10890	628.4	2.6	1253	0.6	4.2	44.5	1.8	27.9	5.8	ND	ND
	VKD-119	10890	628.4	2.6	1253	0.6	4.2	44.5	1.8	27.9	5.8	ND	ND
	VKD-124	14890	725.6	3.3	1354	0.8	3.0	48.3	11.0	19.2	2.7	ND	ND
Snowgeese	VKG-099	11560	608.0	2.6	1736	0.9	2.3	35.1	1.8	11.4	1.1	ND	ND
	VKG-103	11980	608.0	2.6	1736	0.9	2.3	35.1	1.8	11.4	1.1	ND	ND
	VKG-104	12780	369.5	ND	1531	0.7	2.9	41.2	1.3	11.4	0.8	ND	ND
	VKG-105	11690	428.6	3.4	2005	1.0	2.2	30.3	1.2	9.8	1.1	ND	ND

^a Not detected

The lungs of pintail ducks and snowgeese collected in the Sacramento Valley were also analyzed (Table 24). In contrast, lung samples from the Sacramento Valley had elevated levels of lead. The snowgoose (VKG-534) had 27.9 ppm in the lung, 58.7 ppm in the liver (Table 6), and 142.7 ppm in the kidney (Table 15). This animal obviously had lead contamination throughout its body.

Brains of pintail ducks, snowgeese, and Canada geese from the Sacramento Valley had high concentrations of potassium, compared to other organs, and relatively low levels of other elements (Table 25).

The data on brain analyses from miscellaneous duck species collected in the Imperial Valley are shown in Table 26. An unusually high concentration of lead in the mallard duck brain (VKD-072) was not accompanied by the presence of lead in the liver, the only other organ available for this animal (Table 7). Because of the low turnover of materials in the brain, it is possible that lead contamination remains in this organ after it has cleared the visceral organs (liver and kidney), and it may be a valuable indicator of past exposure. Typically the bones sequester lead for long periods after exposure unless the animal is female and has laid eggs. The egg-laying process appears to mobilize bone-complexed lead during the remobilization of skeletal calcium.

Calculations of Mean and Median Values

The means of trace element concentrations in liver are listed in Tables 27 and 28. In Tables 29 and 30 concentrations in the kidney are shown. The mean trace element concentrations in the livers of waterfowl from the Imperial Valley are tabulated in Table 27. Mean concentrations of iron, nickel, bromine, and rubidium in the shoveler duck are unusually high when

Table 24. Trace element concentrations in lungs from waterfowl collected in the Sacramento Valley.

ug/g dry weight (ppm)													
Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb	Sr	Pb
Pintail duck	VKD-514	11950	393.0	84.3	2007	1.8	5.8	34.7	1.5	39.0	6.0	1.0	ND ^a
	VKD-520	12340	373.0	3.2	890	0.8	4.8	54.8	2.2	45.5	8.2	ND	11.3
Snowgoose	VKG-501	11240	376.8	1.9	1631	0.9	3.2	38.7	1.7	67.3	6.2	ND	7.3
	VKG-523	8663	277.6	2.7	1245	0.7	1.8	28.1	ND	17.2	4.6	ND	ND
	VKG-533	12280	389.8	4.0	1686	0.9	2.5	42.1	2.3	32.8	6.1	ND	ND
	VKG-534	14370	585.0	3.1	1099	0.6	3.9	56.6	3.2	61.3	8.2	ND	27.9

^a Not detected

Table 25. Trace element concentrations in brains of waterfowl collected in the Imperial and Sacramento Valleys.

ug/g dry weight (ppm)													
Location	Species	Specimen	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb	Pb
Imperial Valley	Pintail	VKD-004	19800	136.5	2.1	121	ND ^a	39.3	49.1	2.8	8.1	6.6	ND
		VKD-009	21560	87.4	2.4	113	0.6	19.4	52.4	1.0	4.1	5.5	ND
		VKD-044	22080	126.6	1.7	133	ND	18.3	55.9	3.6	6.3	4.5	ND
		VKD-045	16470	ND	2.1	143	ND	24.7	47.8	3.8	5.4	7.0	1.6
		VKD-118	19030	112.9	2.0	94	ND	9.9	46.5	4.5	1.0	2.3	ND
		VKD-124	18510	149.2	1.7	112	ND	18.4	44.7	4.5	2.1	1.5	ND
Imperial Valley	Snowgeese	VKG-099	19800	177.6	ND	103	ND	9.9	42.8	1.6	ND	ND	ND
		VKG-104	20300	97.6	ND	76	ND	12.8	46.1	1.3	0.7	ND	ND
		VKG-105	18550	176.6	2.0	86	ND	7.0	43.1	1.3	ND	1.0	ND
	Canada Geese	VKG-140	17900	334.1	ND	147	ND	16.2	48.6	0.9	3.0	1.1	ND
		VKG-144	18010	121.7	1.4	10	ND	7.7	47.1	0.6	1.0	ND	ND
		VKG-145	17410	200.9	ND	117	ND	12.8	46.0	0.8	2.1	ND	ND
	Pintail	VKD-514	19930	156.3	1.6	93	ND	18.2	49.2	0.6	5.1	5.2	ND
		VKD-520	18060	83.8	1.6	72	ND	11.7	46.4	1.6	5.9	6.3	4.8
Imperial Valley	Snowgeese	VKG-501	21820	225.6	ND	822	ND	17.4	50.7	1.2	10.3	5.8	ND
		VKG-523	21550	109.0	1.5	136	ND	13.3	52.8	ND	4.0	5.5	ND
		VKG-533	22920	1127.0	2.3	152	ND	14.7	50.5	2.0	5.8	5.4	ND

^a Not detected

Table 26. Trace element concentrations in the brains from miscellaneous species of waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)

Species	Specimen	K	Ca	Fe	Cu	Zn	As	Se	Br	Rb	Sr	Pb
Canvasback	VKD-002	17000	180.0	101	10.1	43.6	ND ^a	1.2	12.2	2.7	0.2	ND
Widgeon	VKD-008	17600	73.4	74	11.7	46.0	0.6	1.8	1.7	2.5	0.4	ND
	VKD-025	16200	103.0	97	13.3	42.3	0.5	1.5	1.6	4.6	1.1	ND
Baldpate	VKD-017	17400	100.0	98	14.7	41.5	ND	4.8	2.8	1.8	0.4	12.21
Baldpate	VKD-029	17200	95.0	141	9.5	46.6	ND	3.6	5.7	3.0	0.2	ND
Bufflehead	VKD-068	17400	103.0	102	9.1	47.2	ND	1.1	25.2	28.2	0.3	ND
	VKD-040	16900	131.0	90	9.2	47.8	ND	2.0	4.6	2.5	1.2	ND
Redhead	VKD-070	16700	ND	81	6.8	41.5	ND	1.2	6.8	6.1	0.7	ND
	VKD-041	16800	92.1	66	10.4	44.6	1.1	2.5	5.5	7.3	0.5	ND
Mallard	VKD-072	16600	308.0	108	15.7	44.7	ND	4.0	5.3	6.2	ND	581.0
Goldeneye	VKD-074	17400	ND	82	11.1	47.8	ND	2.7	7.1	16.3	0.3	ND
Cinnamon Teal	VKD-125	16600	102.0	99	15.3	44.8	ND	1.7	10.1	6.2	0.4	ND

^a Not detected

Table 27. Mean trace element concentrations in livers from waterfowl collected in the Imperial Valley.

		ug/g dry weight (ppm)												
Species	Number													
	Sampled	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
Pintail	36	10125	166.6	16.8	2949	1.2	122.3	153.8	1.6	11.2	9.1	6.3	2.0	25.2
		(36) ^a	(35)	(36)	(36)	(35)	(36)	(36)	(5)	(36)	(36)	(36)	(1)	(6)
Gr.W. Teal	34	9394	169.0	16.0	2451	1.1	92.8	125.4	1.2	15.0	14.0	5.3	0.8	5.4
		(34)	(33)	(22)	(34)	(21)	(34)	(34)	(4)	(34)	(34)	(34)	(14)	(12)
Shoveler	15	12036	192.0	20.0	6447	2.5	54.8	153.4	1.5	15.6	24.6	11.4	0.8	3.9
		(15)	(15)	(15)	(15)	(15)	(15)	(15)	(9)	(15)	(15)	(15)	(1)	(2)
Ruddy duck	10	11890	137.7	20.2	2415	1.1	140.5	134.9	1.4	49.5	5.0	3.4	ND ^b	40.4
		(10)	(10)	(10)	(10)	(10)	(10)	(10)	(1)	(10)	(10)	(9)		(3)
Canada goose	5	9602	201.4	9.7	1137	0.6	42.2	140.7	ND	3.7	4.7	5.1	0.4	ND
		(5)	(5)	(2)	(5)	(2)	(5)	(5)		(5)	(5)	(3)	(1)	
Snowgoose	18	10969	155.5	10.3	2387	1.1	65.0	127.2	ND	5.1	3.6	2.3	ND	4.4
		(18)	(18)	(18)	(18)	(18)	(18)	(18)		(18)	(18)	(16)		(1)

^a Number in parentheses is the number of birds in which the element was detected

^b Not detected

Table 28. Mean trace element concentrations in livers of land and aquatic birds collected in the Imperial Valley.

ug/g dry weight (ppm)														
Species	Number	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
Sparrowhawk	6	9791 (6) ^b	956.5 (5)	10.1 (4)	686 (6)	0.6 (1)	22.8 (6)	88.1 (6)	ND ^a	4.4 (6)	4.8 (6)	3.6 (6)	2.6 (5)	ND
Pheasant	3	11203 (3)	411.3 (2)	8.8 (2)	563 (3)	0.6 (1)	15.2 (3)	100.3 (3)	ND	2.2 (3)	3.9 (3)	5.2 (3)	1.5 (1)	ND
Roadrunner	5	11810 (5)	194.9 (5)	16.1 (5)	810 (5)	0.6 (4)	19.2 (5)	120.0 (5)	1.3 (1)	7.9 (5)	6.1 (5)	3.7 (5)	ND	ND
Pelican	1	13150	448.8	11.1	1157	ND	35.7	252.5	ND	4.3	16.1	ND	ND	ND
Gt.Bl. Heron	1	13050	232.5	16.0	2913	1.6	22.3	152.4	1.2	11.3	11.1	11.7	ND	ND
Cal. Gull	6	9789 (6)	337.6 (6)	ND	1446 (6)	ND	12.5 (6)	78.4 (6)	ND	7.4 (6)	6.4 (6)	8.1 (6)	1.9 (6)	1.7 (1)

^a Not detected

^b Number in parentheses is the number of birds in which the element was detected

compared to other species. Copper and selenium are high in the ruddy duck. The highest percentage of waterfowl containing lead were the green-wing teal and the ruddy duck; these ducks also had the highest individual concentrations which skewed the mean values upward. Iron concentrations in waterfowl are several times higher than in land birds but not higher than in aquatic birds (Table 28). Also, copper and selenium tend to be higher and arsenic more prominent in the livers of waterfowl than land birds. These relationships will be discussed in a later section.

The mean concentrations of trace elements in the kidneys of the waterfowl and land birds collected in the Imperial Valley (Tables 29 and 30) show a higher frequency of lead in this organ than in the livers of waterfowl (Table 27). Arsenic is absent in the land bird's kidneys and nickel is low.

The mean trace element concentrations in the liver and kidneys of waterfowl collected in the Imperial and Sacramento Valleys are compared in Table 31. The sample sizes for each species are not large, but some differences between the species from the Sacramento Valley and those from the Imperial Valley are evident in the aggregate data, i.e., arsenic is absent in Sacramento Valley waterfowl and present in those from the Imperial Valley. This may be related to the lack of use of arsenical compounds in the Sacramento Valley and their use in the Imperial Valley as a defoliant for cotton.

We can see that mean differences between the two populations of wintering waterfowl are in calcium, iron, copper, zinc, bromine, rubidium, and lead concentrations in the livers, and in calcium, selenium, bromine, rubidium, and lead concentrations in the kidneys. The element-rich Imperial Valley and Salton Sea environments, with distinctive parent materials and

Table 29. Mean trace element concentrations in kidneys from waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)														
Species	Number	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
Pintail	32	12011	303.6	12.9	556	0.6	30.2	98.8	1.7	11.0	15.2	10.7	5.9	8.3
		(32) ^a	(31)	(32)	(32)	(28)	(32)	(32)	(6)	(32)	(32)	(32)	(3)	(13)
Gr.W. Teal	34	11111	307.4	16.1	513	0.7	24.9	96.5	1.3	15.4	23.3	8.4	1.8	4.3
		(34)	(31)	(18)	(34)	(13)	(34)	(34)	(7)	(34)	(34)	(33)	(19)	(20)
Shoveler	15	12497	306.4	11.2	640	0.7	21.9	106.8	1.3	12.9	36.2	13.7	1.7	12.6
		(15)	(15)	(15)	(15)	(14)	(15)	(15)	(3)	(15)	(15)	(15)	(3)	(2)
Ruddy duck	10	13352	353.8	15.3	692	0.7	19.8	90.8	5.9	70.6	11.6	4.0	1.3	273.0
		(10)	(10)	(10)	(10)	(10)	(10)	(10)	(3)	(10)	(10)	(10)	(1)	(5)
Can. Goose	8	10663	255.4	10.0	574	ND ^b	12.9	80.5	1.2	3.8	7.2	3.9	0.7	0.9
		(8)	(8)	(5)	(8)		(8)	(8)	(1)	(8)	(8)	(6)	(3)	(1)
Snow goose	18	14873	317.8	9.8	768	0.6	21.9	108.0	1.0	4.6	8.5	2.7	1.8	6.3
		(18)	(18)	(18)	(18)	(16)	(18)	(18)	(3)	(18)	(18)	(18)	(2)	(4)

^a Number in parentheses is the number of birds in which the element was detected

^b Not detected

Table 30. Mean trace element concentrations in kidneys from land and aquatic birds collected in the Imperial Valley.

ug/g dry weight (ppm)														
Species	Number	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
Sparrowhawk	6	5425	545.0	ND ^a	432	ND	30.7	81.9	ND	4.5	8.5	4.9	5.8	65.6
		(6)	(3)		(6)		(6)	(6)		(5)	(6)	(6)	(4)	(2)
Pheasant	4	10832	618.0	7.4	634	0.6	12.1	76.7	ND	3.5	6.6	4.4	1.8	5.9
		(4)	(4)	(3)	(4)	(2)	(4)	(4)		(4)	(4)	(4)	(1)	(3)
Roadrunner	4	9125	543.0	ND	427	ND	23.3	74.4	ND	7.1	11.4	5.5	ND	9.6
		(4)	(1)		(4)		(4)	(4)		(4)	(4)	(4)		(1)
Calif. Gull	6	9280	1114.3	ND	509	ND	14.3	93.2	ND	8.6	10.7	7.6	8.0	1.8
		(6)	(6)		(6)		(6)	(6)		(6)	(6)	(6)	(6)	(2)

^a Not detected

^b Number in parentheses is the number of birds in which the element was detected

Table 31. Comparison of mean trace element concentrations in liver and kidney from waterfowl collected in the Imperial and Sacramento Valleys.

ug/g dry weight (ppm)																
Organ	Species	Number	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb	N
Liver	Snowgoose	IV ^a	10970	155.5	10.3	2387	1.1	65.0	127.2	ND ^c	5.2	3.6	2.3	ND	4.4	18
		SV ^b	9798	174.1	16.1	2721	1.2	136.0	170.5	ND	5.1	20.7	7.8	ND	58.7	4
	Gr.W. Teal	IV	9395	169.0	16.0	2451	.1	92.8	125.4	1.2	15.0	14.0	5.3	0.8	5.4	34
		SV	7689	469.9	8.0	1164	ND	79.1	80.0	ND	2.8	30.6	25.7	9.2	ND	7
	Shoveler	IV	12036	192.0	20.0	6447	2.5	54.8	153.4	1.5	15.6	24.6	11.4	0.8	3.9	15
		SV	9352	216.0	10.9	3099	ND	58.3	107.1	ND	5.1	57.6	7.4	0.6	4.6	11
	Pintail	IV	10125	166.6	16.8	2949	1.2	122.3	153.8	1.6	11.2	9.1	6.3	2.0	25.2	36
		SV	11026	184.4	26.9	3646	1.9	102.1	234.3	ND	3.6	14.8	7.9	ND	23.5	2
Kidney	Snowgoose	IV	14873	317.8	9.8	768	0.6	21.9	108.0	1.0	4.6	8.5	2.7	1.8	6.3	18
		SV	9167	172.6	6.7	963	0.7	14.3	70.5	ND	3.8	20.5	8.7	ND	142.7	2
	Gr.W. Teal	IV	11111	307.4	16.1	513	0.7	24.9	96.5	1.3	15.4	23.3	8.4	1.8	4.3	34
		SV	11446	541.5	10.5	522	1.1	22.3	91.6	ND	5.3	45.2	47.3	2.1	2.5	7
	Shoveler	IV	12497	306.1	11.2	640	0.7	21.9	106.8	1.3	12.9	36.2	13.7	1.7	12.6	15
		SV	10878	281.0	ND	519	ND	19.4	85.7	ND	5.8	78.5	10.1	0.7	1.7	11
	Pintail	IV	12011	303.6	12.9	556	0.6	30.2	98.8	1.7	11.0	15.2	10.7	5.9	8.3	32
		SV	10968	205.5	13.1	511	0.6	38.8	92.9	ND	7.2	21.8	11.7	ND	31.8	2

^a Imperial Valley

^b Sacramento Valley

^c Not detected

intensive agricultural activity, and the centripetal drainage of the Imperial Valley desert basin are some obvious reasons for the differences noted in the same species inhabiting each area. Whether or not these basic geochemical differences influence the trace element composition of wintering waterfowl is a crucial point in this study. Our data appear to support the hypothesis that the occurrence of several elements considered essential and others non-essential for normal physiology of the waterfowl is influenced by their presence in the wintering environment of the Imperial Valley.

A comparison of mean trace element concentrations in the liver and kidneys of waterfowl, land birds, and gulls from the Imperial Valley can be seen in Table 32. The major differences in the concentrations of trace elements in the livers of these birds are the high mean concentrations of iron, nickel, copper, and selenium in the waterfowl, the higher mean concentrations of calcium in the land birds, and the presence of strontium in the gulls.

The frequency, mean, maximum, and minimum concentrations of selected trace elements are given in Table 33 for liver and kidneys of Imperial Valley waterfowl, land birds, and gulls. The kidneys of the ruddy duck, the only diving duck in the statistical analysis, contained the maximum concentrations of arsenic, selenium, and lead.

TRACE ELEMENT ANALYSES OF WINTERING AREAS

We examined the trace elements in the soils of the two valleys to obtain more information on the influence of parent materials on wintering waterfowl that would support the hypothesis discussed above. Surface soil (0-7.5 cm) was collected in the fields of the northern portion of the Imperial Valley

Table 32. Comparison of mean trace element concentrations in liver and kidney from waterfowl, land birds, and aquatic birds collected in the Imperial Valley.

ug/g dry weight (ppm)															
Organ	Bird Type	Number	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
Liver															
	Waterfowl	118	10670	170.4	15.5	2981	1.3	74.8	139.2	ND ^a	15.2	10.2	5.6	ND	(20%) ^b
	Land birds	14	10935	520.9	11.7	686	0.6	19.1	102.8	ND	4.4	4.9	4.2	ND	(0)
	Gulls	6	9790	337.6	ND	1446	ND	12.5	78.4	ND	7.4	6.4	8.1	1.9	(17%)
Kidney															
	Waterfowl	117	12418	307.4	12.5	624	ND	21.9	96.9	2.1	19.7	17.0	7.2	2.2	(38%)
	Land birds	14	8461	568.7	ND	501	ND	22.0	77.7	ND	5.0	8.8	4.9	ND	(43%)
	Gulls	6	9270	1114.3	ND	509	ND	14.3	93.2	ND	8.6	10.7	7.6	8.0	(33%)

^a Not detected

^b Frequency of occurrence in samples

Table 33. Special trace elements in liver and kidney from waterfowl, land, and aquatic birds collected in the Imperial Valleys

ug/g dry weight (ppm)																		
Organ	Species	No.	Ni				As				Se				Pb			
			Z ^a	X	Max	Min	Z	X	Max	Min	Z	X	Max	Min	Z	X	Max	Min
Liver	Pintail	36	97.2	1.2	2.1	0.5	13.9	1.6	2.3	1.0	100	11.2	32.9	3.6	16.7	25.2	133.3	1.0
	Gr.W. Teal	34	61.7	1.1	1.6	0.6	11.8	1.5	1.5	1.0	100	15.0	38.9	5.8	35.3	5.4	40.2	0.7
	Shoveler	15	100	2.5	4.3	0.9	60	1.5	3.4	0.8	100	15.6	24.9	9.7	13.3	3.9	5.9	2.0
	Ruddyduck	10	100	1.1	2.5	0.5	10	1.4	^b	-	100	49.5	144.8	11.4	30	40.4	97.3	3.1
	Can. Goose	5	40	0.6	0.7	0.6	ND ^c	ND	ND	ND	100	3.7	4.5	2.8	ND	ND	ND	ND
	Snow goose	18	100	1.1	2.1	0.7	ND	ND	ND	ND	100	5.1	11.0	2.3	5.5	4.4	-	-
	Sparrow Hawk	6	17	0.6	-	-	ND	ND	ND	ND	100	4.4	5.8	2.7	ND	ND	ND	ND
	Road Runner	5	80	0.6	0.7	0.5	20	1.3	1.3	-	100	7.9	11.2	4.0	ND	ND	ND	ND
	Calif. Gull	6	6	ND			ND				100	7.4	11.5	4.1	17	1.7	-	-
	Pheasant	3	33	0.6	-	-	ND				100	2.2	2.4	2.0	ND	ND	ND	ND
Kidney	Pintail	35	87.5	0.6	0.9	0.5	18.7	1.7	4.3	0.9	100	11.0	29.7	3.6	40.6	8.3	67.8	0.9
	Gr.W. Teal	34	38.2	0.7	0.9	0.5	20.6	1.3	1.6	0.9	100	15.4	41.7	8.3	58.8	4.3	20.1	1.0
	Shoveler	15	93.3	0.7	1.0	0.5	20.0	1.3	1.9	0.9	100	12.9	20.0	8.1	13.3	12.6	21.8	3.5
	Ruddy duck	10	100	0.7	1.7	0.5	30	5.9	11.9	1.1	100	70.6	294.2	12.6	50	273.0	886.3	2.3
	Can. goose	5	ND				12.5	1.2	-	-	100	3.8	4.6	3.0	12.5	0.9	-	-
	Snow goose	18	88.9	0.6	0.9	0.5	16.7	1.0	-	-	100	4.6	6.3	3.6	22.2	6.3	17.0	1.1
	Sparrow Hawk	6	ND				ND				83	4.5	7.7	2.6	33.3	65.6	93.4	37.8
	Road Runner	5	ND				ND				100	7.1	8.5	5.4	25	9.6	-	-
	Calif. Gull	6	ND				ND				100	8.6	15.4	8.1	33.3	2.8	4.4	1.1
	Pheasant	4	ND	0.6	0.7	0.6	ND				100	3.5	4.1	2.9	75	5.9	10.9	2.3

^a Frequency of occurrence in samples^b Not applicable^c Not detected

adjacent to the Salton Sea Wildlife Refuge where waterfowl feed. We collected soil samples on various radii to a distance of three miles from a developing geothermal well site and calculated the concentrations of trace elements. The mean value of 32 samples and frequency of occurrence, standard deviations, and maximum and minimum concentrations are in Table 34. In 13% of the samples nickel is at a concentration above the expected value of the crustal abundance in soils.^{16,26} It occurs at frequencies of 38-100% in the livers and kidneys of the waterfowl sampled. Arsenic, selenium, and strontium are present in 100% of the soil samples but are observed in the waterfowl organs at a lower frequency. Elements in the table that occur in waterfowl are designated with an asterisk. Waterfowl that graze in agricultural fields, such as snowgeese, Canada geese, and pintail ducks would be expected to exhibit a correlation of their trace element concentrations and that of the surface soil of the region.

The trace element concentrations in the surface soil in the Sacramento National Wildlife Refuge near Willows, California are tabulated in Table 35. Concentrations of rare earths, rubidium, strontium, chlorine, and magnesium are lower in the Sacramento Valley soil than in the Imperial Valley soil. The Sacramento Valley soil sample was obtained from one area, however, and does not represent the range of concentrations present in the valley.

We also determined the trace element composition in suspended and bottom sediments in the Salton Sea because the waterfowl species in the Imperial Valley would have some exposure to these materials in their eating habits (Table 36). Diving ducks may feed almost exclusively in the Salton Sea shoreline habitats and should show a strong correlation with the bottom

Table 34. Trace elements in surface soils of the Northern Imperial Valley.

ug/g dry weight (ppm)

Element	Frequency %	Mean Concentration (ppm)	Standard Deviation (ppm)	Maximum (ppm)	Minimum (ppm)
Na	100	7193	2422	15590	4504
Mg	100	20087	4535	32950	14170
Al	100	49239	15698	64890	10210
Cl	87	2443	4000	18200	2
K*	100	18477	1089	20500	15560
Ca*	100	47309	6342	5430	35340
Sc	100	9.4	0.9	10.0	7.2
Ti	90	3057	794	4501	101
V	87	75	22	101	30
Cr	10	49	5	61	42
Mn*	100	468	27	540	422
Fe*	100	26689	2490	30700	20500
Co	100	10	0.8	11	8
Ni*	13	35	5	42	31
Zn*	100	89	10	117	68
Ga	83	19	4	30	12
As*	100	9.1	1.6	16.0	6.3
Rb*	100	116	11	132	92
Sr*	100	258	28	341	218
Zr	100	134	37	259	72
Mo	93	2.5	1.5	10.0	4.9
In	50	1.6	3.7	12.0	0.1
Sb	100	0.9	0.1	1.0	0.7
Cs	100	6.8	0.8	8.1	4.9
Ba	100	511	54	649	437
La	100	32	3	37	21
Ce	100	64	4	71	56
Nd	100	29	2	32	25
Eu	100	0.8	0.1	0.9	0.7
Hf	100	5.1	0.6	7.2	4.3
Th	100	10.3	0.7	11.6	8.8
U	100	2.9	0.3	3.5	2.2

* Occur in waterfowl

Table 35. Trace element concentrations in surface soil of the Sacramento National Wildlife Refuge.

Element	ug/g dry weight (ppm)	
	Concentration,	Analytical error ^a
	ppm	ppm
Na	14170	119
Mg	7809	880
Al	52430	1610
K	11190	422
Ca	6340	20950
Sc	13.6	0.1
Ti	3615	332
V	104.8	4.3
Cr	111.1	1.2
Mn	417	3
Fe	31550	189
Co	14.9	0.1
Ni	46.8	14.7
Zn	72.4	3.5
Ga	12.5	3.3
As	6.8	0.6
Br	3.8	0.6
Rb	52.2	3.1
Sr	173.5	27.8
Zr	106	38
Cl	123	41
Cs	2.4	0.1
Ba	450	23
La	15.7	0.3
Ce	30.7	0.8
Nd	14.3	0.8
Eu	0.68	0.01
Hf	3.67	0.08
Th	4.04	0.05
U	1.77	0.17

^a Error of analysis by neutron activation analysis

Table 36. Trace element concentrations in suspended and bottom sediments in the Salton Sea.

Element	ug/g dry weight (ppm)	
	Suspended Sediments, ppm	Bottom Sediments, ppm
Na	87830	13840
Mg	ND ^a	17940
Al	ND	52640
Cl	10670	9739
K	ND	16740
Ca	54370	63520
Sc	5.23	9.23
Ti	ND	2734
V	ND	115.4
Cr	69.0	42.7
Mn	552	349
Fe	15510	25500
Co	6.2	8.7
Ni	4.6	ND
Zn	202	73
As	14.7	6.8
Se	1.7	0.72
Br	90.6	6.1
Rb	62.7	86.3
Sr	410.6	361.1
Zr	ND	158.1
Sb	1.5	0.8
Cs	4.2	7.2
Ba	250	477
La	17.9	27.6
Ce	34.1	60.8
Th	5.5	9.8
U	2.2	3.5

^a Not detected

sediments. These elements and those in the surface soil are the major source of inorganic materials that enter waterfowl directly.

The suspended sediments were filtered from 4.4 liters of water onto a Nucleopore filter (0.45 microns). The sediments were retrieved from the filter and analyzed by instrumental neutron activation (Table 36). Bottom sediments were obtained in the southern portion of the Salton Sea with a lucite push-tube core sampler of our own design.

It is apparent that Salton Sea bottom sediments are enriched in certain trace elements over that occurring in the water column. Numerous metals such as vanadium, iron, magnesium, and aluminum occur in higher concentrations in the bottom sediments of the Salton Sea, probably because of flocculation and sedimentation. Barium, lanthanum, and cerium are also enriched in the bottom sediments.

STATISTICAL ANALYSIS

The statistical parameters of the trace element concentrations observed in the kidneys of Imperial Valley waterfowl and aquatic bird species are listed in Table 37. In skewed or non-Gaussian frequency distributions, as these typically are, the median is often a more useful indicator of population midpoint and average elemental concentration. Mean values are moved upward by outlying high values which occur in many of the frequency distributions. Diagrams of the elemental distributions for five species are shown in Figures 1 through 20. The aggregation of the data and the outlying measurements as well as the relationships between species for a given element can be seen in these scatterplots of the data. More detailed statistical analyses of these data will be made and discussed in a separate report.

Table 37. Statistics of trace element concentrations in kidneys from waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)																
Organ	Number Analyzed	Statistic	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb	
Pintail Duck	32	X	12011	304	12.9	556	0.6	30.2	98.8	1.7	11.0	15.2	10.7	5.9	8.3	
		Maximum	15040	1363	18.7	886	0.9	46.1	136.5	4.3	28.7	32.5	21.9	13.8	67.8	
		Median	12300	244	13.3	555	0.6	30.5	100.5	1.3	9.5	14.3	10.6	3.2	2.3	
		Minimum	8400	156	7.1	213	0.5	12.8	70.7	0.9	3.6	5.8	3.0	0.7	0.9	
		Nc	32	31	32	32	28	32	32	6	32	32	32	3	13	
Shoveler duck	15	X	12497	306	11.2	640	0.7	21.9	106.8	1.3	12.9	36.2	13.7	1.7	12.6	
		Maximum	14810	748	13.0	1577	1.0	38.8	155.5	1.9	20.0	91.5	31.3	3.0	21.8	
		Median	12630	275	11.1	569	0.7	21.0	99.2	1.1	12.2	26.2	10.6	1.4	12.6	
		Minimum	9909	150	9.8	305	0.5	13.2	75.6	0.9	8.1	8.8	2.6	0.7	3.5	
		N	15	15	15	15	14	15	15	3	15	15	15	3	2	
Ruddy duck	10	X	13352	354	15.3	692	0.7	19.8	90.8	5.9	70.6	11.6	4.0	1.3	273.0	
		Maximum	14620	753	21.7	845	1.7	34.6	98.8	11.9	294.2	16.4	5.4	---	886.0	
		Median	13500	267	14.6	691	0.6	17.7	91.1	4.7	27.7	10.8	4.5	---	20.3	
		Minimum	11540	216	11.2	444	0.5	15.2	82.9	1.1	12.6	8.3	1.2	---	2.3	
		N	10	10	10	10	10	10	10	3	10	10	10	1	5	
Gr.Winged Teal	34	X	11111	307	16.1	513	0.7	24.9	96.5	1.3	15.4	23.3	8.4	1.8	4.3	
		Maximum	13760	727	21.8	1027	0.9	42.3	118.2	1.6	41.7	90.1	18.2	5.9	20.1	
		Median	11535	279	16.6	486	0.6	21.8	97.3	1.2	13.6	17.7	7.3	1.3	1.8	
		Minimum	6679	164	12.0	310	0.5	11.2	68.9	0.9	8.3	8.9	3.6	0.8	1.0	
		N	34	31	18	34	13	34	34	7	34	34	33	19	20	
Snowgoose	18	X	14873	318	9.8	758	0.6	21.9	108.0	1.0	4.6	8.5	2.7	1.8	6.3	
		Maximum	18700	427	13.6	1316	0.9	42.0	181.9	1.0	6.3	11.6	4.0	2.7	17.0	
		Median	14875	324	9.9	743	0.6	20.3	103.4	1.0	4.6	8.1	2.8	1.8	3.6	
		Minimum	12350	186	6.0	489	0.5	13.0	83.7	1.0	3.6	6.5	0.8	0.9	1.1	
		N	18	18	18	18	16	18	18	3	18	18	18	2	4	
Canada Goose	8	X	10663	255	10.0	574	ND ^b	12.9	80.5	---	3.8	7.2	3.9	0.7	ND	
		Maximum	13760	439	11.7	829	ND	15.3	96.6	---	4.6	11.2	8.6	0.9	ND	
		Median	9956	225	10.1	561	ND	12.9	82.2	---	3.6	6.1	1.9	0.8	0.9	
		Minimum	8472	145	8.0	334	ND	9.9	64.0	1.2	3.0	5.1	1.2	0.5	ND	
		N	8	8	5	8		8	8	1	8	8	6	3	1	

^a Statistic not calculable^b Not detected

Figure 2. Scatterplot of potassium concentrations in the livers of Imperial Valley waterfowl.

Figure 3. Scatterplot of calcium concentrations in the livers of Imperial Valley waterfowl.

Figure 4. Scatterplot of manganese concentrations in the livers of Imperial Valley waterfowl.

Figure 5. Scatterplot of iron concentrations in the livers of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL LIVER -NI

Figure 6. Scatterplot of nickel concentrations in the livers of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL LIVER -CU

Figure 7. Scatterplot of copper concentrations in the livers of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL LIVER -ZN

Figure 8. Scatterplot of zinc concentrations in the livers of Imperial Valley waterfowl.

Figure 9. Scatterplot of selenium concentrations in the livers of Imperial Valley waterfowl.

Figure 10. Scatterplot of bromine concentrations in the livers of Imperial Valley waterfowl.

Figure 11. Scatterplot of rubidium concentrations in the livers of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL KIDNEY -K

Figure 12. Scatterplot of potassium concentrations in the kidneys of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL KIDNEY -CA

Figure 13. Scatterplot of calcium concentrations in the kidneys of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL KIDNEY -MN

Figure 14. Scatterplot of manganese concentrations in the kidneys of Imperial Valley waterfowl.

Figure 15. Scatterplot of iron concentrations in the kidneys of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL KIDNEY -NI

Figure 16. Scatterplot of nickel concentrations in the kidneys of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL KIDNEY -CU

Figure 17: Scatterplot of copper concentrations in the kidneys of Imperial Valley waterfowl.

IMPERIAL VALLEY WATERFOWL KIDNEY -ZN

Figure 18. Scatterplot of zinc concentrations in the kidneys of Imperial Valley waterfowl.

Figure 19. Scatterplot of bromine concentrations in the kidneys of Imperial Valley waterfowl.

Figure 20. Scatterplot of rubidium concentrations in the kidneys of Imperial Valley waterfowl.

The highest median concentrations of selenium and arsenic (Table 37) occurred in the ruddy duck, which also had the highest lead concentrations in the series of waterfowl. The shoveler duck had the highest median values for nickel, bromine, and rubidium in the kidneys, which were also high in the liver of the species. The snowgeese exhibited the highest median concentrations of potassium, iron, and zinc. The gulls are characterized by their high median concentrations of calcium, arsenic, and strontium.

Trace element concentrations in the livers of waterfowl and aquatic birds from the Imperial Valley were also summarized (Table 38). The highest median concentration for iron, nickel, zinc, and rubidium were in the shoveler duck. Highest median values for manganese, iron, nickel, zinc, bromine, and rubidium were also in the shoveler duck livers. The ruddy duck had the highest median values for potassium, copper, and selenium.

We also summarized the trace element concentrations in the livers and kidneys of Sacramento Valley waterfowl species (Table 39). The pintail duck had the highest median concentrations of manganese, iron, nickel, zinc, and lead in the liver. In the kidney, highest median values in the green-winged teal were observed for potassium, calcium, and rubidium. The shoveler duck had high values for metals in the Imperial Valley, whereas the pintail duck exhibited maximum median values for these elements in the Sacramento Valley. Since the two areas are quite distinct from the standpoint of physiography, geological and erosional history, sedimentation, and water chemistry, there is an adequate basis for different trace element patterns in the waterfowl as the result of feeding habits and exposure to different substratum materials. The high level of agricultural and irrigation outfall from the Imperial Valley to the Salton Sea, the prime waterfowl habitat,

Table 38. Statistics of trace element concentrations in liver from waterfowl collected in the Imperial Valley.

ug/g dry weight (ppm)

Organ	Number Analyzed	Statistic	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb
Pintail Duck	36	X	10125	167	16.8	2949	1.2	122.3	153.8	1.6	11.2	9.1	6.3	2.0	25.2
		Maximum	12300	630	23.8	5321	2.1	612.5	290.7	2.3	32.9	24.9	18.5	---	133.3
		Median	10050	142	16.7	2911	1.3	108.5	140.4	1.3	8.7	7.3	5.6	---	3.2
		Minimum	6604	59	8.0	702	0.5	30.0	56.3	1.0	3.6	2.4	1.8	---	1.0
		N ^b	36	35	36	36	35	36	36	5	36	36	36	1	6
Shoveler duck	15	X	12036	192	20.0	6447	2.5	54.8	153.4	1.5	15.6	24.6	11.4	0.8	3.9
		Maximum	15020	345	26.3	11490	4.3	160.0	275.4	3.4	24.9	60.2	24.6	---	5.9
		Median	11580	184	20.9	6752	2.3	57.4	143.8	1.3	14.1	20.3	10.0	---	3.9
		Minimum	10160	110	13.4	1778	0.9	12.6	111.6	0.8	9.7	6.3	0.8	---	2.0
		N	15	15	15	15	15	15	15	9	15	15	1	---	2
Ruddy duck	10	X	11890	138	20.2	2415	1.1	140.5	134.9	1.4	49.5	5.0	3.4	ND ^c	40.4
		Maximum	13840	264	28.5	6250	2.5	365.1	168.1	---	144.8	8.7	5.1	ND	97.3
		Median	11665	128	20.3	1943	1.0	115.5	132.3	---	41.4	4.8	3.7	ND	20.6
		Minimum	9210	86	13.2	624	0.5	55.3	91.3	---	11.4	2.2	2.0	ND	3.1
		N	10	10	10	10	10	10	10	1	10	10	9	ND	3
Gr. Winged Teal	34	X	9395	170	16.0	2451	1.1	92.8	125.4	1.2	15.0	14.0	5.3	0.8	5.4
		Maximum	13690	530	22.8	7787	1.6	255.5	230.0	1.5	38.9	62.0	14.2	2.5	40.2
		Median	9333	139	16.0	2321	1.1	86.0	127.5	1.2	11.9	10.4	4.4	0.6	0.6
		Minimum	5725	45	6.7	801	0.6	13.3	68.7	1.0	5.8	3.0	2.1	0.4	0.4
		N	34	33	42	34	21	34	34	4	34	34	34	14	12
Snowgoose	18	X	10970	155	10.3	2387	1.1	65.0	127.2	ND	5.1	3.6	2.3	ND	4.4
		Maximum	14440	432	17.0	5398	2.1	101.3	195.5	ND	11.0	12.1	10.3	ND	---
		Median	11025	147	9.7	2142	1.0	63.7	125.8	ND	4.9	3.0	1.7	ND	---
		Minimum	6865	51	6.6	614	0.7	16.3	74.0	ND	2.3	2.0	0.9	ND	---
		N	18	18	18	18	18	18	18		18	18	16		1
Canada Goose	8	X	9602	201	9.7	1137	0.6	42.2	140.7	ND	3.7	4.7	5.1	0.4	ND
		Maximum	10810	239	9.8	1759	0.7	81.0	213.1	ND	4.5	7.5	7.9	---	ND
		Median	9763	205	9.7	942	0.6	24.8	113.1	ND	3.8	4.5	5.6	---	ND
		Minimum	8192	152	9.6	496	0.6	11.4	95.8	ND	2.8	2.1	1.8	---	ND
		N	5	5	2	5	2	5	5		5	5	3	1	

^a Statistic not calculable^b Number of animals in which element occurred^c Not detected

Table 39. Statistics of trace element concentrations in liver and kidney from waterfowl collected in the Sacramento Valley.

ug/g dry weight (ppm)															
Species	Organ	No. ^a	Statistic	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb	Sr	Pb
Pintail duck	Liver	2	X	11026	184.4	26.9	3646	1.9	102.1	234.4	3.6	14.8	7.9	ND ^b	23.5
			Maximum	12400	289.2	35.2	3826	2.2	134.6	274.2	4.7	17.6	8.0	ND	44.6
			Median	11028	184.4	26.9	3646	1.9	102.1	234.2	3.6	14.8	7.9	ND	23.5
			Minimum	9653	79.6	18.7	3465	1.6	69.5	194.5	2.5	11.9	7.7	ND	2.5
			N ^c	2	2	2	2	2	2	2	2	2	2		2
	Kidney	2	X	10968	205.5	13.1	511	—	38.8	92.9	7.2	21.8	11.7	ND	31.8
			Maximum	12200	220.6	14.1	591	—	44.8	95.6	10.8	22.4	15.1	ND	60.2
			Median	10968	205.5	13.1	511	—	38.8	92.2	7.2	21.8	11.7	ND	31.8
			Minimum	9376	109.4	12.2	430	—	32.7	90.2	3.7	21.3	8.3	ND	3.4
			N	2	2	2	2		2	2	2	2	2		2
Shoveler	Liver	11	X	9352	216.0	10.9	3099	ND	58.3	107.1	5.1	57.6	7.4	0.6	4.6
			Maximum	10840	502.8	16.4	5789	ND	84.2	133.1	7.4	88.3	11.9	1.0	6.7
			Median	9217	191.8	10.4	2826	ND	56.8	109.5	5.0	54.0	5.6	0.5	4.9
			Minimum	8694	128.3	4.9	1569	ND	23.1	82.4	3.2	35.5	4.8	0.3	2.1
			N	11	11	8	11		11	11	11	11	11	6	3
	Kidney	12	X	10878	281.0	ND	519	ND	19.4	85.7	5.8	78.5	10.1	0.7	1.9
			Maximum	11710	384.6	ND	845	ND	25.1	99.8	7.0	148.1	15.0	1.3	6.2
			Median	10800	280.8	ND	478	ND	20.7	84.8	5.9	67.4	8.8	0.5	0.8
			Minimum	10200	185.1	ND	339	ND	12.3	68.5	4.0	36.3	6.2	0.3	0.8
			N	12	12		12		12	12	12	12	12	11	5
Gr. Wing Teal	Liver	7	X	7689	469.9	8.0	1164	ND	79.1	80.0	2.8	30.6	25.7	9.2	ND
			Maximum	9414	2138.0	11.2	2182	ND	182.7	135.5	8.9	115.6	82.8	17.9	ND
			Median	7717	144.3	8.0	843	ND	64.9	90.7	1.5	17.9	15.8	9.2	ND
			Minimum	5130	85.8	4.8	470	ND	28.5	42.4	0.7	8.6	3.8	0.4	ND
			N	7	6	2	7		7	7	7	7	7	2	

^a Number of animals sampled^b Not detected^c Number of animals in which element occurred^d Statistic not calculable

Table 39. Statistics of trace element concentrations in liver and kidney from waterfowl collected in the Sacramento Valley.

(Cont'd)

ug/g dry weight (ppm)															
Species	Organ	No. ^a	Statistic	K	Ca	Mn	Fe	Ni	Cu	Zn	Se	Br	Rb	Sr	Pb
	Kidney	7	X	11446	541.5	10.5	522	1.1	22.3	91.6	5.3	45.2	47.3	2.1	2.5
			Maximum	12170	1110.0	--- ^d	800	---	31.7	104.8	11.0	124.1	154.0	6.8	4.8
			Median	11510	356.7	---	516	---	20.3	95.7	4.8	33.7	28.5	1.0	2.3
			Minimum	10500	266.2	---	342	---	16.0	71.9	2.8	21.6	7.2	0.4	0.7
			N	7	7	1	7	1	7	7	7	7	7	5	4
Snowgoose	Liver	4	X	9798	174.1	16.1	2721	1.2	136.0	170.5	5.2	20.7	7.8	ND ^b	58.7
			Maximum	11420	241.1	19.4	4994	1.8	186.7	212.3	7.5	30.1	8.7	ND	---
			Median	9733	171.1	15.5	2366	1.2	151.2	179.9	5.8	18.8	8.1	ND	---
			Minimum	8306	113.2	13.8	1158	0.8	54.9	110.1	1.6	15.1	6.5	ND	---
			N ^c	4	4	4	4	4	4	4	4	4	4		1
	Kidney	2	X	5167	172.6	6.7	963	0.7	14.3	70.5	3.8	20.5	8.7	ND	142.7
			Maximum	10650	195.5	7.4	966	0.9	16.2	73.3	6.6	21.1	9.9	ND	---
			Median	9167	172.6	6.7	963	0.7	14.3	70.5	3.8	20.5	8.7	ND	---
			Minimum	7684	149.7	6.0	960	0.6	12.5	67.7	1.0	19.9	7.4	ND	---
			N	2	2	2	2	2	2	2	2	2	2		1

^a Number of animals sampled^b Not detected^c Number of animals in which element occurred^d Statistic not calculable

creates a trace element milieu that is unique in California's waterfowl habitats. In addition, the sediments underlying the Imperial Valley and the Salton Sea basin are the erosional products of the Colorado River and from diverse igneous and sedimentary rock types. At the present time, the agricultural outfall of the lower Colorado River Valley is also imported to the Imperial Valley via the All American Canal, which supplies the irrigation water to the Imperial Valley. These factors create strong basic substratum, and biogeochemical differences between the two California areas which will be reflected in the trace element burdens of animals inhabiting the two areas, even on a migratory basis. Radioisotope data obtained from the study of migratory waterfowl wintering at the Savannah River nuclear facility on the east coast of the United States indicate that within one month, waterfowl acquire equilibrium levels of radionuclides in an aquatic environment.²⁷

The trace elements in five organs of pintail ducks and snow-geese from the Imperial Valley are compared (Table 40). We see that maximum concentrations of each element generally occur in the accumulating, or target, organ. Potassium is consistently at the highest concentration in the brain of the five organs analyzed; calcium in the lung; iron, nickel, manganese, copper, and zinc in the liver; and selenium in the liver or kidney. The lung always had the highest concentration of bromine, suggesting that it arrives by an inhalation pathway, and rubidium is usually the highest in the kidney, occasionally highest in the liver. Except for the occurrence of bromine in the lungs, these distribution patterns are well-recognized in mammalian studies.

Table 40. Comparison of trace element concentrations in five organs from pintail ducks and snowgeese collected in the Imperial Valley.

ug/g dry weight (ppm)														
Date	Specimen	Organ	K	Ca	Fe	Ni	Cu	Zn	Se	Br	Rb	Mn	Pb	Sr
23 Oct. 75	VKD-004	Liver	10080	132.4	2554	1.2	138.4	141.7	7.9	20.9	8.2	16.8	ND ^a	ND
		Kidney	11980	192.4	539	0.4	32.1	99.9	9.7	32.5	16.1	14.4	ND	ND
		Brain	19800	136.5	136	ND	39.3	49.1	2.8	8.1	6.5	2.1	ND	ND
		Lung	11240	307.7	1507	0.9	5.4	37.8	4.9	53.6	7.3	2.8	ND	ND
	VKD-007	Liver	9935	156.6	3508	1.3	74.5	117.5	7.3	13.7	11.7	19.2	ND	ND
		Kidney	12740	338.6	489	0.6	18.3	83.7	6.5	18.5	15.1	13.0	ND	ND
		Brain	*b											
		Lung	11960	598.8	1367	0.9	2.9	45.9	6.9	20.2	5.9	2.0	1.8	1.6
		Heart	9945	94.2	228	ND	11.9	51.4	1.2	12.2	9.4	ND	ND	ND
	VKD-009	Liver	11170	98.8	2918	1.3	135.4	163.0	3.6	7.8	6.8	17.5	ND	ND
		Kidney	13800	342.8	434	0.8	43.4	114.3	5.0	18.9	9.3	11.3	ND	ND
		Brain	21560	87.4	113	0.6	19.4	52.4	0.9	4.1	5.5	2.4	ND	ND
		Lung	13910	663.9	1372	0.9	4.4	52.0	1.7	30.1	5.5	3.6	ND	ND
		Heart	10700	82.5	300	0.8	15.3	69.8	0.8	10.6	5.1	2.2	ND	ND
1 Nov. 75	VKD-044	Liver	11060	198.3	2857	1.0	71.6	117.1	13.3	14.0	4.9	15.9	ND	ND
		Kidney	*											
		Brain	22080	126.6	133	ND	18.3	55.9	3.6	6.2	4.5	1.7	ND	ND
		Lung	11780	586.3	1288	0.9	4.0	51.4	10.9	44.5	3.7	1.6	ND	ND
		Heart	*											
	VKD-045	Liver	8007	ND	3521	ND	171.4	172.2	8.9	11.1	5.9	11.9	ND	ND
		Kidney	9379	ND	574	ND	22.3	79.1	7.9	16.9	10.5	9.1	2.3	ND
		Brain	16470	ND	143	ND	24.7	47.8	3.8	5.4	6.9	2.1	ND	0.5
		Lung	8869	461.1	977	ND	4.3	43.5	5.1	27.8	6.4	ND	1.6	2.3
		Heart	10190	ND	271	ND	16.6	66.2	4.3	10.9	6.9	2.1	ND	ND
	VKD-048	Liver	10500	187.2	2905	1.4	61.9	100.2	5.9	10.9	6.4	11.7	ND	ND
		Lung	12980	480.7	1438	0.7	3.0	45.6	4.3	31.7	4.3	2.9	ND	ND
		Heart	13050	89.0	318	0.4	19.6	79.6	3.3	13.1	4.9	1.8	ND	ND

^a Not detected

Table 40. Comparison of trace element concentrations in five organs from pintail ducks and snowgeese collected in the Imperial Valley.
(Cont'd)

ug/g dry weight (ppm)														
Date Collected	Specimen	Organ	K	Ca	Fe	Ni	Cu	Zn	Se	Br	Rb	Mn	Pb	Sr
18 Jan 76	VKD-118	Liver	9757	178.5	5321	2.1	114.1	123.0	23.8	6.3	1.9	15.3	ND ^a	ND
		Kidney	10630	187.0	653	0.5	22.9	81.4	21.9	8.7	4.8	13.4	0.9	ND
		Brain	19030	112.9	94	ND	9.9	46.5	4.5	1.0	2.3	2.0	ND	ND
		Lung	11540	517.9	1553	0.7	2.9	33.2	11.6	14.4	2.4	2.2	ND	1.2
	VKD-119	Liver	9858	137.4	4364	1.9	169.8	159.0	6.3	6.6	6.1	16.1	1.0	ND
		Kidney	12720	199.4	407	0.6	40.8	118.5	8.6	14.7	15.5	14.3	2.9	ND
		Lung	10890	628.4	1253	0.6	4.2	44.4	1.8	27.9	5.8	2.6	ND	ND
		Heart	11180	37.8	248	ND	17.8	76.9	1.4	8.2	6.6	1.6	ND	ND
	VKD-124	Liver	11800	175.6	4256	1.7	61.3	154.6	16.9	7.9	2.5	18.4	2.0	ND
		Kidney	13660	235.0	647	0.7	34.9	111.7	16.5	12.9	4.7	14.7	4.3	ND
		Brain	18510	149.2	113	ND	18.4	44.7	4.5	2.1	1.5	1.7	ND	ND
		Lung	14890	726.0	1354	0.8	3.0	48.3	10.9	19.2	2.7	3.3	ND	ND
		Heart	11620	66.0	296	ND	14.6	63.9	5.6	7.6	2.2	2.0	ND	ND
	VKG-099	Liver	11280	164.6	5398	2.1	16.3	103.4	11.0	12.1	10.3	12.9	ND	ND
		Kidney	12350	213.5	631	0.6	20.5	10.1	4.6	8.1	2.9	7.1	ND	ND
		Brain	19800	177.5	103	ND	9.9	42.8	1.6	ND	ND	ND	ND	ND
		Lung	11560	476.7	1736	0.7	2.2	35.1	1.7	11.8	1.4	1.9	ND	ND
17 Jan 76 Snowgeese	VKG-104	Liver	8966	59.4	614	0.7	19.3	74.0	2.2	2.5	1.5	6.6	ND	ND
		Kidney	14870	210.8	558	0.6	16.9	93.2	4.0	6.9	2.7	8.8	2.0	ND
		Brain	20300	97.6	76	ND	12.8	46.1	1.3	0.7	ND	ND	ND	ND
		Lung	12780	369.5	1531	0.7	2.9	41.2	1.3	0.8	ND	ND	ND	ND
	VKG-105	Liver	12470	156.6	1794	0.7	101.3	163.0	4.8	3.6	1.9	8.7	ND	ND
		Kidney	14160	224.1	897	0.6	22.1	117.5	4.5	10.2	1.9	10.4	ND	ND
		Brain	18550	176.6	86	ND	7.8	43.1	1.3	ND	1.0	2.0	ND	ND
		Lung	11690	428.6	2005	1.0	2.2	30.3	1.2	9.7	1.1	3.4	1.2	ND
		Heart	13450	133.0	380	0.5	19.8	96.3	2.0	6.7	1.6	2.0	ND	ND

^a Not detected

DISCUSSION

We obtained data on trace elements in waterfowl and land birds inhabiting an area being developed for geothermal power. These data provide a biogeochemical baseline that is related to existing baselines in the Imperial Valley agro-ecosystem and also related to expected geothermal effluents. The existing biogeochemical baselines are mainly derived from the basic geochemistry of the region, i.e., alluvial sediments of the Imperial Valley, and from agricultural and other activities.

Two large obvious influxes of materials into the Imperial Valley affect the biogeochemical baseline being studied. These are importation of irrigation water with its suspended sediment load and agricultural chemical outfall from the Colorado River Valley and the intensive agricultural activities of the Imperial Valley itself.

The elements detected in the waterfowl and bird species in this study may be classified into three groups:

- o The essential elements required for basic physiological functions, usually present in higher concentrations, such as potassium, calcium, iron, copper, and zinc;
- o The required trace elements such as manganese, nickel, arsenic, and selenium; and
- o The non-essential trace elements which may be geochemical or anthropogenic in origin, such as bromine, rubidium, strontium, and lead.

Arsenic and nickel are considered to be anthropogenic, at least in part, in the Imperial Valley biogeochemical baseline.

It is apparent from the analytical data presented in this report on waterfowl and other bird groups that elements related to human activities (anthropogenic) are present in these bird populations. Some of these elements, such as arsenic ($LD_{50} = 3 \text{ mg/kg}$) and lead, are toxic in relatively low concentration; and others, such as nickel and selenium, if required, are essential in very low amounts. Essential elements are toxic at higher concentrations than required.²⁸

Elements related to geothermal resource development, and any subsequent effluent, may fall in any of the three groups described above and exert deleterious effects upon plants and animals when present in high concentrations. Elements detected in waterfowl and believed to have anthropogenic sources in the Imperial Valley ecosystem are nickel, arsenic, bromine, and lead. Nickel originates in the 110,000 tons of triple phosphate fertilizer used in the Imperial Valley (1975 rate). Other elements prominent in the phosphatic fertilizer used widely in California are calcium, vanadium, iron, zinc, strontium, cadmium, and uranium.²⁹

Bromine is present in many pesticides such as DBCP (di-bromo-chloro-propane) and ethylene dibromide used on cotton and lettuce. Over 24 tons of brominated compounds were used in the Imperial Valley in 1975. Two of the largest sources of anthropogenic elements released in the Imperial Valley are phosphatic fertilizers and brominated pesticides. Arsenic is used in the form of cacodylic acid on cotton as a defoliant prior to harvesting; previously arsenic was in general use as a pesticide.

Other elements released in as large or larger quantities are fluorine, sulfur, phosphorus, and chlorine. The latter are two primarily in

organophosphate and chlorinated hydrocarbon pesticides. We did not analyze for these pesticides in the samples used in this study.

Another large source of elements imported into the Imperial Valley is the irrigation water, which contains a small but easily quantitated sediment load. Because of the large amount of water brought into the Imperial Valley for irrigation, on the order of four acre-feet per year, this imported sediment, and the elements it contains, contributes a large influx of trace materials to the Imperial Valley ecosystem.

Lead in most environments, exclusive of a low geochemical level, originates from automotive emissions. This source far outweighs any regional technological source except on a local basis near mining operations. Waterfowl populations are usually exposed to lead in the form of spent lead shot from hunting. Fortunately most of the hunting is confined to regulated hunting areas; therefore, the wetland lead contamination is somewhat localized. The lead shot is ingested with sediments and food organisms, especially those in sediments. Roadside animals are exposed to automotive lead and absorb it when they ingest plant foliage covered with lead particles and also when they inhale the roadside atmosphere. These modes of intake circumvent the soil-root pathway, which is not particularly effective for lead transfer, and places the deposited lead either directly in the gastro-intestinal tract of the animal or in the lungs where uptake occurs at a higher rate than in the intestinal tract. High concentrations of lead are known to occur along heavily-travelled roads, and wild and domestic grazing animals are contaminated with it in these areas.^{23,30}

A fraction of the automotive lead is apparently more volatile and is transported longer distances than that which falls out adjacent to roads and highways. Because of this long range source of anthropogenic lead, any

environment that is downwind from a major metropolitan area may receive measurable quantities of lead from automotive sources. In a study of a remote sector of Yosemite National Park, Hirao and Patterson⁷ found that lead was deposited at 18 kg per hectare each year in an alpine watershed and was detectable in plants and animals in the ecosystem. Its automotive source was identified by mass spectroscopy.

Selenium is present in most of the birds analyzed and its source is believed to be primarily geochemical, i.e., in the soils and parent materials from which the soils were derived. Western United States soils are typically high in this element; it is taken up and concentrated by certain plant genera such as Astragalus or vetch and bound to amino acids (methionine).³¹

The elements found in geothermal brine are listed in Table 41. Several of these elements have multiple sources in the Imperial Valley ecosystem. Since geothermally-labelled groundwater may occur to the surface of the ground in northern Imperial Valley³², the assumption of an already existing environmental source of geothermal elements is justified. As an example, strontium is present in the geothermal brine, phosphatic fertilizers, and the soils or alluvium covering the Imperial Valley. The geochemical source in the soils is probably the strongest, but it would be difficult to separate it from the general labelling of soil materials in the northern Imperial Valley with groundwater containing geothermal elements. The chemical state of each source would also have a strong effect upon the elements availability to biological systems.

The nickel observed in the birds we analyzed is undoubtedly derived from the phosphatic fertilizers used in the Imperial Valley. Nickel is not detected deep in the soils, and only the surface 15 cm usually contains it.³³

Table 41. Elemental Composition of Geothermal Brine

Element	Concentration ^a ppm	Sinclair #3 well 6922 ^b Concentration, ppm
Cl	560,000	93,650
Na	231,000	36,340
Ca	100,000	14,550
K	58,000	7,820
Fe	8,100	--**
Mg	6,000	780
Zn	3,100	--
Sr	2,400	360
Si	1,500	--
B	1,500	210
Ba	900	540
Li	800	49
Rb	500	--
Br	500	--
Mn	200	410
Cs	100	--
F	100	2
I	100	--
S	100	58***
As	--	10
Pb	--	8

^a Generalized values^b From Palmer, T.

** Not detected

*** As sulphate

The arsenic concentrations in the soil range from 6 to 10 ppm. However, the concentration doubles at a depth of 140 cm suggesting that the element is leached under the highly alkaline soil conditions (pH 8.3 and higher). The use of cacodylic acid currently adds this element to the soil, but the level of use in the Imperial Valley is not particularly high. In the past, however, arsenical compounds were used more in agriculture, and it is very likely that the general baseline for arsenic in agricultural areas is anthropogenically produced. Arsenic is carried in the irrigation water and deposited in the Salton Sea, and Salton Sea sediments and those in rivers contain the highest arsenic concentrations observed in the area.

The patterns of trace element distribution in waterfowl organs conforms to general physiological data on elemental distribution. Most of the available data on elemental distribution pertains to small mammal or human studies.^{16,34} In Table 42, the mean concentrations of trace elements in waterfowl determined in this study are listed with data on man or other mammals, and we can compare these. Bowen¹⁶ lists dry weight concentrations, and these may be compared directly with the waterfowl values, which are also expressed as $\mu\text{g/g}$ dry weight (ppm).

The major differences between waterfowl and mammals appears to be in the higher concentrations of manganese, iron, copper, and selenium in the waterfowl liver, and in higher concentrations of potassium, manganese, iron, copper, and selenium in the kidney. The higher concentrations of selenium in waterfowl organisms is related to its greater abundance in the environment of Imperial Valley.

The levels of certain anthropogenic elements, such as lead, will affect the presence and concentrations of required trace elements.²⁵ A

Table 42. Comparison of trace element concentrations in human, mammalian, and waterfowl organs.

ppm														
Date														
Organ	K	Ca	Mn	Fe	Ni	Cu	Zn	As	Se	Br	Rb	Sr	Pb	Range (Pb)
Liver	2500 ^a	50	1.4	178	0.07	6.7	47	0.1	0.66	2.6	30	0.02	1.7	
	7400 ^b	140	3.7	520	0.02	19.0	130	0.5	2.10	10.0	30	0.06	4.8	
	10860 ^c	165	17.0	3320	1.4	96.0	136	1.4	19.0	12.0	6	1.1		0.8 - 133.0
Kidney	1903 ^a	93	0.9	74	0.05	2.9	484	0.03	0.9	5.5	9	0.06	1.1	
	7800 ^b	390	3.8	290	0.02	12.0	210	0.30	2.1	16.0	17	0.24	4.5	
	12647 ^c	314	13.0	643	0.66	24.0	97	2.3	23.0	19.0	8	1.8		0.9 - 886.0

^a Report of the Task Group on Reference Man, ICRP No. 23, ³⁴ ppm wet wt.

^b Bowen ¹⁶, ppm dry wt.

^c Mean concentrations, this study, ppm dry weight.

population study of the interaction between toxic trace elements and the required elements would clarify some of the relationships which have been determined primarily in laboratory or controlled studies. Protection against lead toxicity, for example, may be effected by selenium, arsenic, sulfur, calcium, phosphorus, and vitamins such as E and D.³⁶

Higher concentrations of bromine, strontium, and nickel than detected in the waterfowl we studied would be required to cause toxic symptoms²⁸ but lead concentrations observed in the waterfowl sampled in this study are within the range of toxic and lethal effects.

Some elemental interrelationships are apparent in these data. Whenever strontium is present in relatively high concentration the animal usually has the highest calcium concentration in the series sampled. The general tendency to accumulate all alkaline metals was noted in early studies of the radionuclide ⁹⁰Sr. Only weak interrelationships are apparent in other element pairs. All elements were plotted against each other and the only significant correlation observed was between iron and nickel, both of which occur in the triple phosphate fertilizer used in the Imperial Valley.

One apparent general correlation is that elevated levels of selenium and arsenic occur whenever high concentrations of lead are observed. Other elements are also elevated in the organs whenever lead is present in high concentration, and it is possible that the animal accumulates many elements from its diet when experiencing lead toxicity.³⁷ Older birds may be expected to have higher concentrations of elements that they integrate and retain throughout their lives, but it is difficult to age birds beyond the first year. Tagging studies such as those being done on distinct populations of waterfowl, i.e., the Dusky Canada goose (Branta canadensis occidentalis),³⁸ could yield information on waterfowl age and trace element accumulation.

Lead exposure and uptake would occur in all age groups and therefore age/lead concentration relationships would show poor correlation. In studies with mallards, Koranda et al.²⁵ found that iron and calcium did accumulate in the organs when ducks were dosed with lead, especially on low calcium diets.

Of all the species studied, the shoveler and ruddy duck are the most unique with respect to the concentrations of trace elements observed in their organs. On the basis of median and mean concentrations of trace elements (Table 29) in the kidney, the ruddy duck has higher concentrations of arsenic, selenium, and lead. The shoveler duck had concentrations of iron, bromine, and rubidium higher than any other species.

On the basis of elemental concentrations in the livers of six species (Table 27), the shoveler duck had high median and mean concentrations of iron, nickel, zinc, bromine, and rubidium. The ruddy duck has high manganese and selenium in the liver. Both the shoveler duck and the ruddy duck are unique in this series of waterfowl species because they live primarily in the aquatic environment, and usually do not venture into the surrounding agricultural environment. The ruddy duck is the only diving duck sampled in large numbers in this study and its high lead concentrations are most likely explained by its habit of searching for food organisms in sediments where lead shot is deposited. The shoveler duck is primarily a plant feeder, eating various species of aquatic plants, such as Potamogeton, Scirpus, Eleocharis, and Distichlis, and invertebrates, mainly mollusks and crustacea.⁴⁰ It is not readily apparent from our data why the shoveler duck has acquired its unique elemental composition, but undoubtedly it is related to the characteristics of its foodchain. Mollusks and crustacea

with their mucous coverings and filtering habits are concentrators of fine suspended and dissolved materials in the water column. As noted previously, aquatic plants also concentrate elements from the water.^{3,4} The food chains and feeding behavior of both these species have produced the elemental concentrations that distinguish them from other species living in the same environment. A summary of waterfowl characteristics of the species in this study is given in Table 43.

A multi-parameter statistical analysis of these data by linear and quadratic discriminant functions was made,³⁹ and it is possible to characterize the ruddy duck, the shoveler duck, and the snowgoose 100% of the time on the basis of their unique elemental composition, and 85% of the time identify pintail and green-winged teal ducks. This analysis will be published in a future report.

SUMMARY

The determination of effects from geothermal resource development in the Imperial Valley upon waterfowl populations must be made with the understanding that complex effects from other sources of elemental contamination are present in that ecosystem. Elements characteristic of the Imperial Valley geochemical background and from agricultural activities in the area are present in waterfowl populations; and the exposure to lead shot in hunting areas adjacent to the Salton Sea may make discrimination of geothermal effluent elements very difficult. Some of the elements expected in geothermal effluents are the same elements present in the regional geochemical background, and the comparison of concentration levels is the only apparent diagnostic character that could be used for this purpose.

Table 43. Characteristics of Waterfowl Species in this study.

<u>Species</u>	<u>Breeding Range</u>	<u>Winter Range</u>	<u>Food habits</u>
Lesser Snowgoose <u>Chen caerulescens</u>	Arctic Canada and Siberia, Few in Arctic Alaska	N.W. United States, Wash., Oregon, and California	Mainly plants, wild aquatic and agricultural
Pintail duck <u>Anas acuta</u>	Central and Arctic Canada, N. Canada	N.W. United States, California to Mexico	Low amount of animal food; mainly wild aquatic and agricultural plants
Green-winged teal <u>Anas crecca</u>	N. Prairies to Alaska	California to Mexico	Invertebrates, molluscs, crustaceans; aquatic plants, mainly seeds
Shoveler duck <u>Anas clypeata</u>	N. Prairies Canada	California to	25% animal food, mollusks, insects, crustaceans; wild aquatic plants
Ruddy duck <u>Oxyura</u> <u>jamaicensis</u>	N. Prairies Canada, U.S.	Pacific Coast Calif. to Mexico	33-100% animal Food, insects, mollusks, crustacea; wild aquatic plants
Canada goose <u>Branta canadensis</u>	N. Prairies Alaska and Canada	Pacific Coast, Central Calif. Valleys	Mainly aquatic and agricultural plants

It is apparent from these data that when a time series of the same species of waterfowl is obtained during a wintering season in the Imperial Valley that the species acquires a higher concentration of nickel, selenium, arsenic, and lead. Samples of waterfowl obtained during October through February in the Imperial Valley show significantly higher concentrations of these four elements at the end of the wintering season. The nickel and arsenic are obtained from agricultural outfall, and the lead is primarily from spent lead shot. Selenium is apparently high in the region and constitutes a local biogeochemical signature, although it is prominent in other parts of the western United States as well.

These data serve to characterize the trace element background in waterfowl wintering in the Imperial Valley. Because of the migratory nature of waterfowl populations, wide variance may be expected in data obtained in the manner used in this study. In spite of these intrinsic sources of variability, the data are quite consistent and, within species and organs, show definite patterns related to basic physiology and feeding behavior of the species. Further studies will reveal how consistent these data are and whether or not great differences occur within other populations of waterfowl using the Pacific Flyway.

Studies of organisms, like waterfowl, that are closely coupled to the biogeochemical characteristics of their environment are important because they provide an assessment of environmental quality. The environment is influenced by many kinds of effluent, i.e., those from geothermal, nuclear, agricultural, and industrial activities. In most ecosystems where effluent from such sources occurs, humans typically occupy a consumer role, and this provides a strong, albeit egocentric, motivation for such studies.

CONCLUSIONS

Trace elements in migratory waterfowl organs obtained in the Imperial Valley and the Sacramento Valley were analyzed and provided a biogeochemical baseline for the developing geothermal resource in this region. Trace elements in soil, sediments, and fertilizer were also studied to determine local fluxes of elements into the Imperial Valley ecosystem and to assess the effects of regional agriculture on the baseline.

Major influxes of trace elements to the Imperial Valley ecosystem are by importing Colorado River water for irrigation, using phosphatic fertilizers, and applying agricultural chemicals. The biogeochemical baseline in Imperial Valley waterfowl populations additionally is affected by the deposition of spent lead shot in the aquatic environments adjacent to the Salton Sea and geothermal well sites.

Waterfowl organs contain several trace elements related to the baseline and the influxes of materials into the Imperial Valley. Nickel, cadmium (data not shown here), and iron from phosphatic fertilizer apparently are present in waterfowl organs as the result of surface and irrigation water transporting these elements to the Salton Sea waterfowl habitats. Some direct contamination from agricultural fields may also occur in species that graze upon land. Elevated bromine and arsenic levels in waterfowl are related to the pesticide and herbicide use in the Imperial Valley. In some waterfowl, especially those that feed in bottom sediments, high lead concentrations are present in the kidney with lower values usually occurring in the liver.

The presence of geothermal-effluent elements in waterfowl will be difficult to demonstrate unless direct contamination of animals and habitats

occurs. The reason for this lies in the characteristics of the geochemical background that already contains geothermal elements, and the complexity and magnitude of the agricultural effluent reaching waterfowl habitats. Unless some obvious trace element "signature" for geothermal effluent is present and can be taken up by plants and animals, it will be difficult to demonstrate a direct relationship between a geothermal release and the animal population's trace element composition. Boron, a prominent element in geothermal effluent not measured in this study, could play an important "signature" role if it is absorbed by the biota.

Mortality in waterfowl populations under present conditions in the Imperial Valley may be caused by lead and avian disease interactions, avian disease and pesticide residue interactions, and climatic factors and avian disease. The Salton Sea area has a history of waterfowl disease episodes resulting from one or more of these factors. Because migratory waterfowl are typically under physiological stress, all of these factors, including a lowered state of health from the rigors of migration, make it very difficult to assess and diagnose any given epizootic episode on the winter range of migratory waterfowl. If there is large scale waterfowl mortality in the Imperial Valley, the causal factors mentioned above should be explored before attributing the problem to geothermal activities, unless direct evidence is available.

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